An Investigation Into Abrasive Resistance of Aluminum 6063, Stainless Steel 316 And Mild Steel Using Taber Linear Abraser And Taber Rotary Abraser

By

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Mechanical Engineering Programme
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In partial fulfilment of the requirement for the
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Approved by,

(AP Dr Mustafar B Sudin)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

December 2010

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MASMALIZA BINTI ZOLKEFLI

ABSTRACT

In many fields of industry, abrasion wear is a dominant wear mechanism that reduces service life of costly machine parts. Therefore, the study upon wear resistance against abrasion actions is often required. In the report, the research done including the theoretically and laboratorial) on "**An Investigation Into Abrasive Resistance of Aluminum 6063, Stainless Steel 316, And Mild Steel Using Taber Linear Abraser And Taber Rotary Abraser**" is been discussed. The objective of this project is to perform abrasive resistance testing using Taber Linear Abraser Model 5750 and Taber Rotary Platform Abraser Model 5131 on Aluminum 6063, Stainless Steel 316, and Mild Steel. The samples are used to investigate their materials behavior on abrasive wear and relate them to the materials properties in term of wear resistance under the selected test conditions. In additions, the laboratory testing also includes the study on surface roughness, hardness, and the wear surface micrograph using optical microscope. Results are compiled and analyzed to further understand the wear characteristic of the materials. The methodology of the study is described in a flow chart which shows steps of data collection, data analysis, ranking of the metallic materials and the conclusion. As the testing has been done, it can be seen that the result of abrasive wear resistivity, surface profile and hardness change are influenced by the hardness of a material. Stainless Steel 316 seems to have the highest abrasive resistivity which is 28.83 Taber wear Index compared Aluminum 6063 as 126.49 and Mild Steel as 78.23 for two body abrasion testing using Taber Rotary Abraser.

The project outcome may actually facilitate the manufacturer to find the suitable metals that can resist the abrasion wear effects. As the abrasion resistance is being fully investigated, the quality and performance of the machinery equipments especially the moving parts will be massively improved.

ACKNOWLEDGEMENT

First and foremost I offer my sincerest gratitude to Allah, the Almighty, on whom ultimately we depend for sustenance and guidance. Alhamdulillah, all praises to Allah for the strengths and His blessing in completing this thesis.

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Thank you,
Masmaliza Bt Zolkefli
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INTRODUCTION

1.1 Background of Study

Wear and friction behavior in moving contacts depend on the properties of the surfaces of the two interacting solids and the material. Wear by abrasion are forms of wear caused by contact between a particle and solid material. The abrasive wear is the loss of material by the passage of hard particles over a surface. Abrasive wear occurs whenever a solid object is loaded against particles of a material that have equal or greater hardness [1]. Any material, even if the bulk of it is very soft, may cause abrasive wear if hard particle are present. The ability to withstand the abrasion wear is specified as abrasive resistance and the basis of abrasive wear resistance of materials is hardness.

1.2 Problem Statement

Contact conditions involving abrasion have long been recognized as being some of the most significant in terms of the amount of material loss [2]. The theoretical understanding of abrasion has advanced considerably. In abrasion, a hard counterbody moves against and partly ploughs through a softer material and thus the hardness of the softer material is of paramount importance. Therefore, the wear resistance against abrasion impact is often required to maintain the material structure, shape of machine components and to extend the lifetime of machinery equipments and parts efficiently [3]. This may includes tools and equipment in daily usage like car pistons, pumps and other sliding machine parts.

1.2.1 Problem Identification

Generally, the study of abrasive resistance is less available in the market place to inform the end user about the performance of the equipments or tools. With appropriate tests and analysis, a better assessment for abrasive resistance characteristics and behavior of a particular metallic material can be determined and documented. Moreover, with this project, it will provide a better mean to look critically and intensely into the improvements and solutions for abrasive wear problems.

1.2.2 Significance of the Project

Failure to identify the abrasive resistances properties of the material might trigger many technical problems in their future application. To optimize the parts' performance, an appropriate study and research including the suitable test should be conducted especially for abrasive resistance properties. Deep study on mechanism of the abrasive is really significant because this wear occurs due to various mechanism and different characteristics.

The abrasive resistance study will assist in the efforts of ensuring the performance of the moving and sliding parts. Abrasive resistance will avoid the part from experiencing material lost. Based on the studies, if a material can resist the occurrence of abrasive wear, the material service life could be longer compared to the others. This study may actually facilitate the selection method of prevention and avoidance of damages to any two or three moving parts. Furthermore, the maintenance cost for the components could be reduced significantly. In additions, this study may actually contribute a lot to the industry as it will discover the details on abrasive wear and its resistances.

1.3 Objectives and Scope Of Study

The objectives of this project are:

- To perform abrasive resistance testing using Taber Linear Abraser Model 5750 and Taber Rotary Platform Abraser Model 5131 on Aluminum 6063, Stainless Steel 316, and Mild Steel.
- To analyze the test results data, compared and rank according to their abrasive resistance properties.

The scope of study is to investigate and understand the characteristic and properties of abrasive wear resistance. To enhance the understanding on this topic, several types of metallic material will be tested and further analyze. This may include the further study and testing on the surface profile, hardness and condition of the surface using optical microscope. Besides, mechanism of abrasive wear also will be additionally studied and evaluated. Searching for information regarding study conducted elsewhere in this field of study through relevant International Journal, Technical Manual, Text Book, and internet is also one of the necessary activities.

1.4 Relevancy of the project

Abrasion wear in particular is a rapid and severe form of wear action and it can result in significant costs if not adequately controlled. Although all the mechanism of abrasive wear shares some common features, there are also some fundamental differences. These differences extend to the practical consideration of materials selection for abrasive wear resistance due to different mechanisms of abrasive wear. The questions are; where is abrasive wear likely to occur? When do these forms of wear occur and how can they be recognized? What are the properties? How to prevent the abrasive wear from happening? To ensure the consistency of the components' performance, serious investigation should be conducted, analyzed and proposed to answer all these questions. The fundamental mechanism involved in the abrasive wear and the protective measures that can be taken against them will be discussed in this project. Since the industry nowadays is facing a lot of problems regarding the abrasive wear, the relevancy of this project is truly higher priority because it may assists a lot in increasing the understanding of abrasive wear resistance itself. This will definitely give exposure and experience to the author as a future engineer as well.

1.5 Feasibility of Project within the Scope and Time Frame

Based on the scope and time frame, it is practicable to complete the project between two semesters duration. All the research and study will be consistently done in the first semester with the guidance of respectful supervisor. After all the theoretical part was completed, selection and purchasing of the material could be done. Familiarization to the lab equipments and procedures also was done in the first semester. Approximately, on the second semester, all the practical works including the lab works was been started. Two months will be provided for the laboratory works purposes. All the findings then has been compiled, analyzed and reported properly in the final dissertation.

Chapter 2

LITERATURE REVIEW

2.1 Abrasive Wear

Abrasive wear is produced by a hard, sharp surface sliding against a softer one and digging out a groove. The abrasive agent may be one of the surfaces (such as a file), or it may be a third component (such as sand particles in a bearing abrading material from each surface). Abrasive wear coefficients are large compared to adhesive ones. Thus, the introduction of abrasive particles into a sliding system can greatly increase the wear rate; automobiles, for example, have air and oil filters to catch abrasive particles before they can produce damage [4]. There are a few uses of the wear phenomenon like in Figure 1 and Figure 2, but in the great majority of cases wear is a nuisance, and a tremendous expenditure of human and material resources is required to overcome the effects [4].

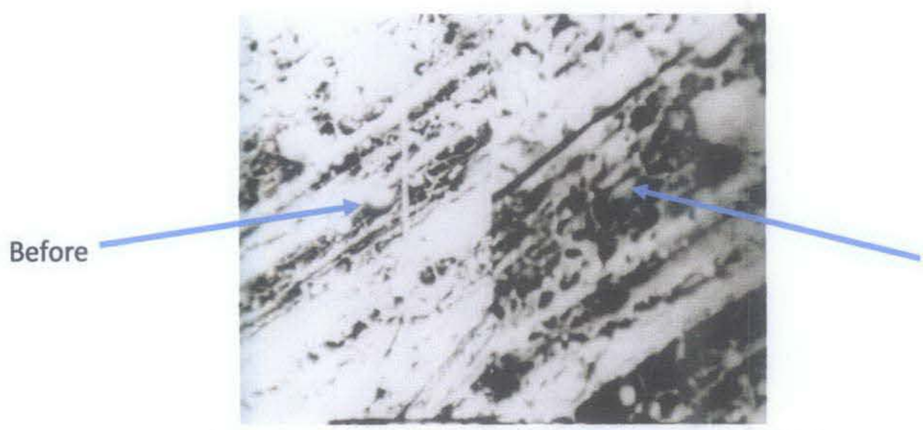


Figure 1: Abrasive Wear Scar Before and After [9]

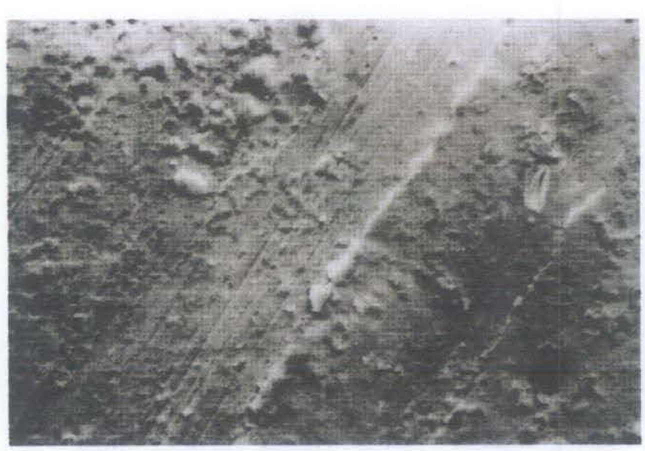


Figure 2: Wear Debris on an abraded surface [9]

2.2.1 Mechanism of Abrasive Wear

It was originally thought that abrasive wear by grits or hard asperities closely resembled cutting by a series of machine tools or a file. However, microscopic examination has revealed that the cutting process is only approximated by the sharpest of grits and many other more indirect mechanisms are involved. The particles or grits may remove material by microcutting, microfracture, and pull out of individual grains or accelerated fatigue by repeated deformations [1] .

In Figure 3, the first mechanism illustrated (a) cutting represents the classic model where a sharp grit or hard asperity cuts the softer surface. The material which is cut is removed as wear debris. When the abraded material is brittle, (b) may occur. In this instance wear debris is the result of crack convergence. When a ductile material is abraded by a blunt grit then cutting is unlikely and the worn surface is repeatedly deformed (c). In this case wear debris is the result of metal fatigue. The last mechanism illustrated (d) represents grain detachment or grain pulls out. In this mechanism the entire grain is lost as wear debris [1]. The effect of hardness on the transition of abrasive wear mechanism of steels is been illustrated in Figure 4.

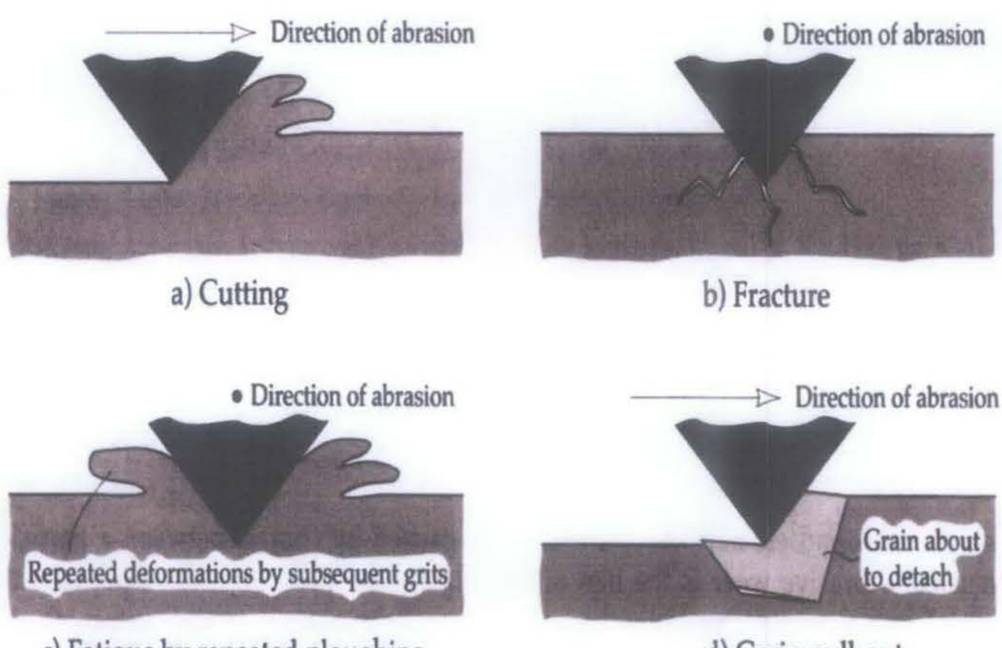


Figure 3: Mechanism of Abrasive Wear [1]

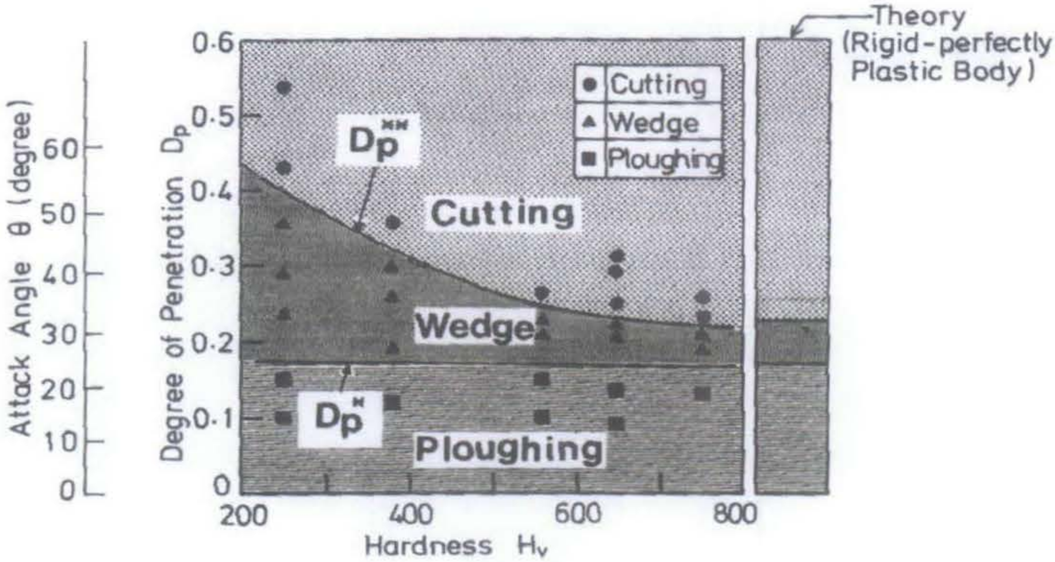


Figure 4: Abrasive Wear Mechanism Diagram [1]

2.2.2 Modes of Abrasive Wear

The way the grits pass over the worn surface determines the nature of abrasive wear [1]. The literature denotes two basic modes of abrasive wear:

- Two-body
- Third-body

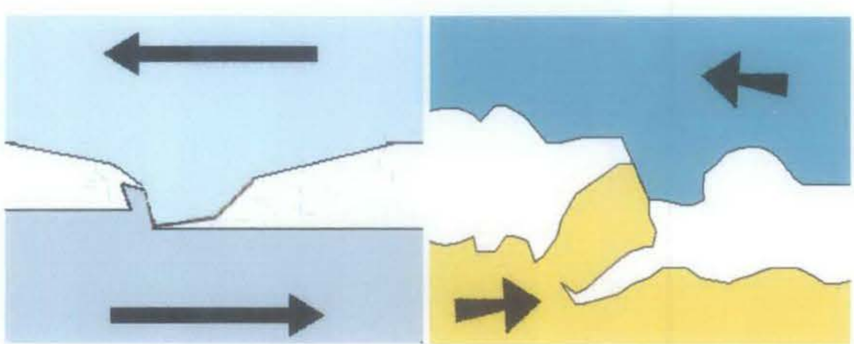


Figure 5: Two-body Abrasion Mode [4]

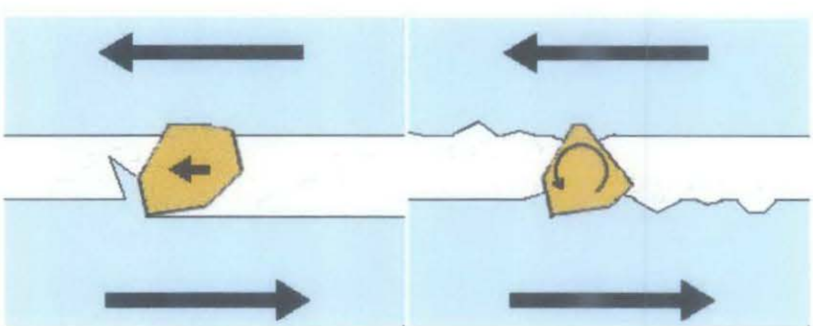


Figure 6: Three-Body of Abrasion Mode [4]

It was found that three-body abrasive wear is ten times slower than two-body wear since it has to compete with other mechanism such as adhesive wear [5]. Properties such as hardness of the backing wheel, which forces the grits onto a particular surface, were found to be important for three-body but not for two-body abrasive wear [1]. Two-body abrasive wear corresponds closely to the cutting tool model of material removal whereas three-body abrasive wear involves slower mechanisms of material removal through very little is known about the mechanisms involved [6]. It appears that the worn material is not removed by a series of scratches as is the case with two-body abrasive wear. Instead, the worn surface displays a random topography suggesting gradual removal of surface layers by the successive contact of grits [7].

2.3 Abrasive Wear Resistance of Stainless Steel, Aluminum 6063, and Mild Steel

Abrasive wear resistance is the ability of a material to withstand mechanical action such as rubbing, scraping, or erosion that tends progressively to remove material from its surface. Such ability helps to maintain the material's original appearance and structure [8]. The basis of abrasive wear resistance of material is hardness and it is generally recognized that hard materials allow slower abrasive rates than softer materials. The abrasive wear resistance of steel can be considerably enhanced by judicious selection of hardness and metallurgical phase. Selection of steel depends on the hardness of the abrasive. For example, if the abrasive is relatively soft, i.e. hardness is less than 1000 [VHN], the it is possible to select a steel of hardness that would be greater than 0.8 X hardness of the abrasive and quenched martensite with a hardness of approximately 800 [VHN] would be suitable.

First, an equation for wear indicates the relative influence of various parameters, such as load hardness, velocity, and surface roughness that suggest changes in wear that might result if the sliding system is changed. Second, comparison of the wear is also important in the failure analysis or in the study of any worn component of a system. Quantitative analysis of wear starts with the concept that while a sliding system may be losing material in more than one way, another mechanism will dominate the overall wear rate [9].

The wear rate is therefore proportional to the load for only a small numbers of variations, but there is still a small deviation between wear rate and load that forms a direct proportionality. The dependence of wear rate, load and pressure was published by Burwell and Strang[10], who concluded that wear rate is proportional to the load and independent of pressure unless the area of contact was equivalent to one-third of the materials' hardness. The most widely used quantitative relationship among abrasive wear rate, material properties, load and sliding speed, at the interface of two bodies loaded against each other in relative motion was formulated by Archard [11]. Archard [11] also reported that wear rates of some materials vary linearly with the applied load and are independent of pressure over a wide range. The widely used quantitative relationship among abrasive wear rate, material properties, load, and sliding speed at the interface between two bodies loaded against each other in a relative motion was formulated by Archard [11].

Based on Carrie K. Harris [2002], Aluminum 6063 may experiences abnormal characteristic when the sliding distance is increased. This abnormality was caused by the increases in temperature during sliding process due to the friction above the plastic range [10]. In the other hands, Stainless Steel 316 wear resistant is superior compared to mild steel. Test under services conditions have been performed on Stainless Steel 316 and mild steel. The test was performed and the reduction of thickness was determined. Result of the two studies shows the superiority of Stainless Steel 316 to mild steel. Stainless Steel 316 also has longer service life compare to mild steel in term of corrosive wear [10]. The balances ductility and strength and has good wear resistance compared to mild steel and it always used for large parts, forging and automotive components [10]. The relationship between wear resistance and hardness is shown is Figure 7.

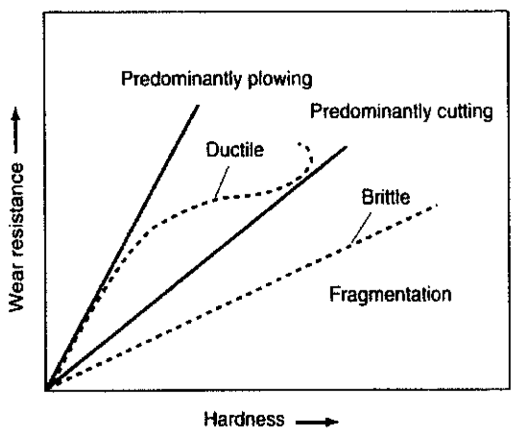


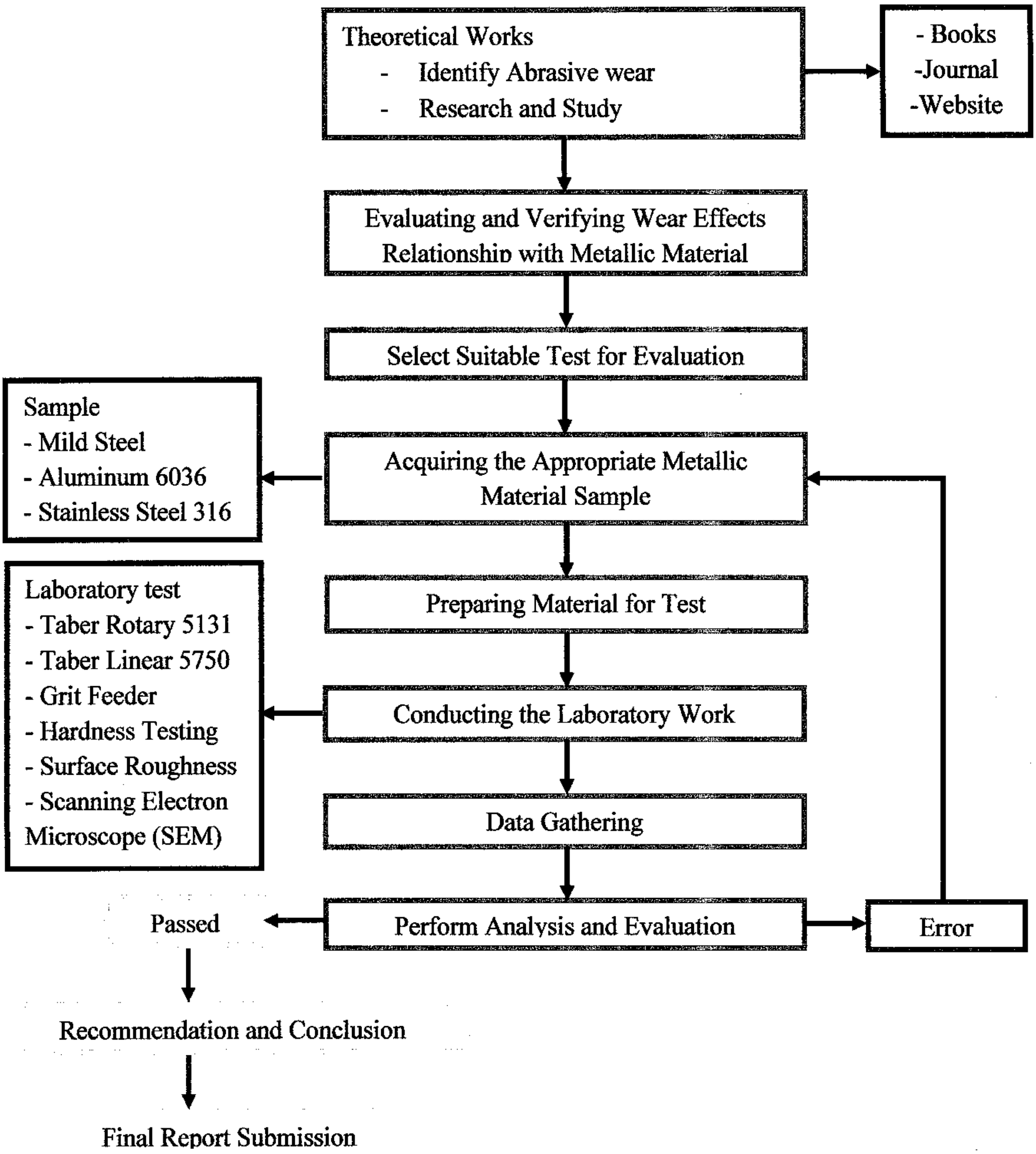
Figure 7: Relation between hardness and different mechanisms of metal removal in abrasive wear. The dotted curve shows the transition behavior for steels. [9]

Chapter 3

METHODOLOGY

3.1 Research Methodology

The systematic method of study that can be applied for this project as followed;



3.3 Gantt Chart and Milestone

For FYP I

No.	Activities	Week														
		1	2	3	4	5	6	7	8	9	MID SEM BREAK	10	11	12	13	14
1.	Selection of Project Topic -Investigation Into Abrasive Resistance Of Metallic Materials															
2.	Preliminary Research Work (Theory)															
3.	Submission of Preliminary Report					Δ										
4.	Evaluating And Verifying Wear -Abrasive Wear															
5.	Select Suitable Test - Taber Linear Abraser - Taber Rotary Abraser (2 and 3 body Abrasion) - Hardness Testing - Surface Profile															
6.	Progress Report and Seminar								Δ							
7.	Acquiring Sample - Mild Steel - Aluminum 6063 - Stainless Steel 316															
8.	Conducting Lab Test - Taber Rotary Two body - Surface Profile - Hardness Testing															
9.	Analysis Result - Graph - Relate back with theory															
10.	Recommendation and Conclusion															
11.	Submission of Interim Report Final Draft															Δ
12.	Oral Presentation															Δ

For FYP II

No.	Activities	Week														
		1	2	3	4	5	6	7		8	9	10	11	12	13	14
1.	**Project Work Continues** - Taber Linear - Taber Rotary (2 body) - Surface Profiler - Hardness Testing								**MID SEMESTER**							
2.	**Submission of Preliminary Report I**					Δ										
3.	**Project Work Continues** - Taber Linear - Taber Rotary (3 body) - Surface Profiler - Hardness Testing															
4.	**Submission of Preliminary Report II**									Δ						
5.	**Seminar**									Δ						
6.	**Project Work Continues** - Analysis and evaluation (Optical Microscope and SEM) - Further analyze the data and compare it with visual data - Poster Preparation(design) - Oral Presentation (slides) - Final Dissertation															
7.	**Poster Exhibition**												Δ			
8.	**Submission of Dissertation Final Draft**															Δ
9.	**Oral Presentation**									*14th May 2010*						
10.	**Submission of Dissertation (hard bound)**									*21st May 2010*						

3.2 Tools /Equipments Required Based On ASTM F1978-00 [2001]

Abrasion resistance measurements of metallic material can be complicated since the resistance to abrasion is affected by many factors. One of these is the physical properties of the material in the metallic metal surface, particularly its hardness and resilience. It can also be affected by conditions of the test (for example, the type and characteristics of the abradant and how it acts on the area of the specimen being abraded, including the development and dissipation of heat during the test cycle). The surface characteristics of the specimen, such as type, depth, and amount of embossing, can likewise affect the abrasion resistance of metallic material [13].

This test method is designed to simulate one kind of abrasive action and abradant that metallic material may encounter in the field. However, results should not be used as an absolute index of ultimate life because, as noted, there are too many factors and interactions to consider. Also involved are the many different types of service conditions. Therefore, the data from this test method are of value chiefly in the development of materials and should not be used without qualifications as a basis for commercial comparisons. This abrasion test method is for flat plate-shaped specimens of a size sufficient that the wheels of the abrader do not leave the surface of the specimen. It is not recommended, however, for devices with other shapes or sizes [13].

The scope of this test may include [13]:

- This test method covers the laboratory procedure for determining the abrasion resistance of metallic material using the Taber Abraser..
- The equipment used in this test method is a modification of the Taber Abraser. A grit-feeding device feeds 240-mesh aluminum silicate grit onto the specimen before it passes under the roller H-10 type. Using the exhaust system incorporated in the apparatus, the used grit and abraded material are continuously removed after passing under both rollers.
- This test method employs a rotary, rubbing action caused by the dual abrading wheels. One wheel rubs the specimen from the center outward and the other from

the outside toward the center. The wheels traverse a complete circle and have an abrasive action on the rotating specimen at all angles. The use of loose grit serves the function of an abradant and also aids in the rolling action felt to be characteristic of normal walking. Wear is quantified as cumulative mass loss.

3.2.1 TABER® Rotary Platform Abraser Model 5131 (Two Mode) [14]

Model 5131 Abrasers are durable, precision built test instruments designed to evaluate the resistance of surfaces to rubbing abrasion. Characteristic rub-wear action of Abrasers is produced by the contact of a test sample turning on a vertical axis, against the sliding rotation of two abrading wheels. The wheels are driven by the sample in opposite directions about a horizontal axis displaced tangentially from the axis of the sample.

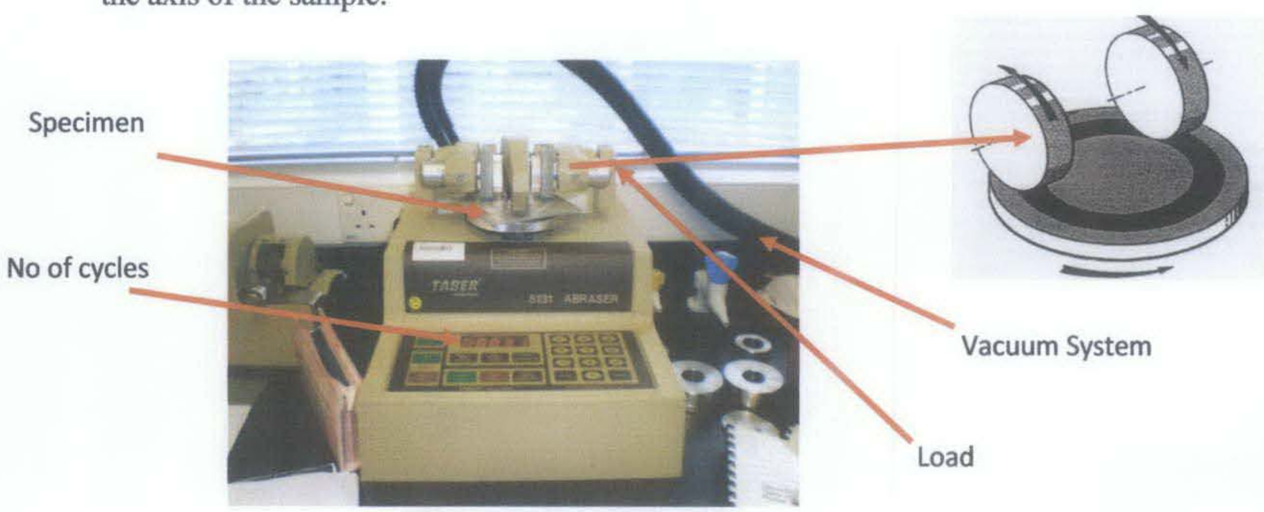


Figure 8: Taber Rotary Platform Abraser Model 5131

3.2.2 Grit Feeder (Three Body Mode) [14]

The Grit Feeder Attachment is used with the Taber Abraser (Abrader) to evaluate three-body abrasion caused by the destructive action of fine, hard particles. The Grit Feeder is a freestanding instrument which is positioned over the Taber Abraser specimen holder. Abrasive grit particles are deposited uniformly and continuously onto the specimen surface. As the specimen holder rotates, the loose grit particles pass under a pair of leather-clad wheels. The resulting rolling action of the particles serves as the abradant and contributes to the physical breakdown of the material. The vacuum hose from the Taber Abraser is inserted into the base of the Grit Feeder allowing a pickup tube to be positioned such that grit particles and debris are removed. The operation of the grit feeder is controlled through the Taber Abraser, ensuring that the turntable, grit distribution and vacuum suction are actuated at the same time.

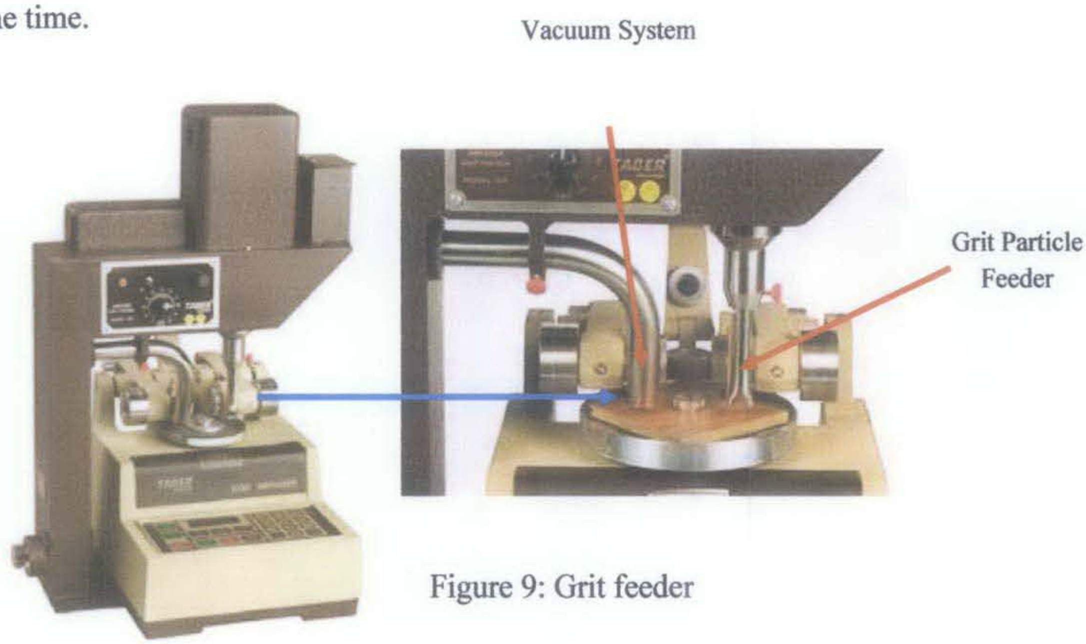


Figure 9: Grit feeder

3.2.3 TABER® Linear Abraser Model 5750 (Two Body Mode)

Designed to test virtually any size or shape specimen, the Linear Abraser is ideal for material properties of contoured surfaces and finished products. Initially developed to evaluate wear resistance, this instrument can also be used to evaluate scratch resistance (single or multiple pass), color transfer [commonly referred to as crocking or a crockmeter], and perform coin scrape tests. In addition, with the universal or a custom attachment, 'real world' testing and other forms of material durability can be performed. The Linear Abraser can be used for both wet and dry testing [14].

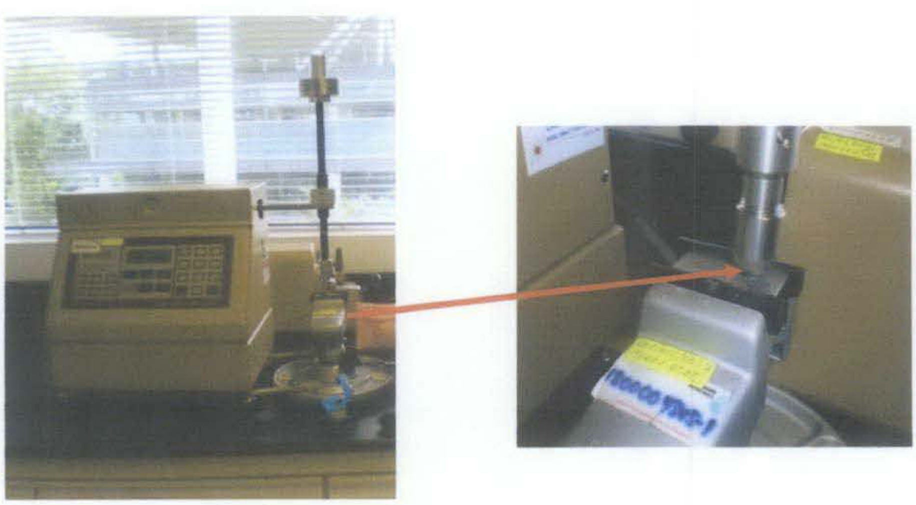


Figure 10: Taber Linear Abraser

A precision bearing on the spline shaft creates a "free-floating head". As the arm strokes in a linear motion, this "free-floating head" follows the contours of the specimen - curved or flat. To enable simulation real world conditions, test parameters can be altered so optimal settings for each material can be established. The Taber® Linear Abraser allows selecting stroke length, speed, and load [14].

3.2.4 Any Other Supporting Equipment/Test

Before and after the sample has gone through Taber Abrader Equipments, the sample then will be further tested using below equipments. Other supporting equipments are important as it will determine the correlation of metallic material properties and abrasive wear impact.

3.2.4.1 Rockwell Hardness Test

The Rockwell Hardness test is a hardness measurement based on the net increase in depth of impression as a load is applied. Hardness numbers have no units and are commonly given in the H, R, L, M, E and K scales. The higher the number in each of the scales means the harder the material.

Figure 11: Rockwell Hardness Test [15]

3.2.4.2 Surface Profiler, Perthometer Mahr Gmbh

Surface roughness can be measured by a surface profiler machine which quantifies the surface roughness i.e. positive deviation from a datum plane (peak) or negative deviation from a datum plane (valley) as well as peaks per inch. The roughness is expressed in micro-inches or micro-meters and expressed as R_a (arithmetic average) or R_z (Mean roughness Depth) values [15].

Figure 12: Surface Profiler

3.2.4.3 Microscope

A microscope is an instrument to see objects that too tiny for the naked eye. The science of investigating small objects using such an instrument is called microscopy. This equipment will help in witnessing the scar or impact of the abrasive wear on the metallic materials [16].

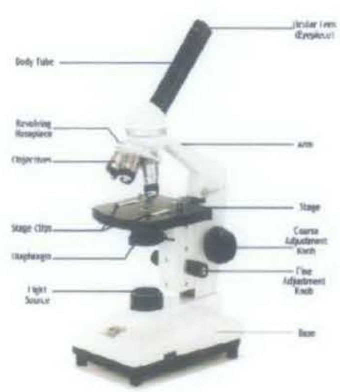


Figure 13 : Microscope [16]

3.2.4.4 Sartorious GD503 Balance

An analytical balance is used to measure mass to a very high degree of precision and accuracy. The weighing pan(s) of a high precision (.01 mg or better) analytical balance are inside a transparent enclosure with doors so that dust does not collect and so any air currents in the room do not affect the balance's operation. [17]

Figure 14: Sartorious GD503 Balanc

3.2.3.2 Scanning Electron Microscope

The scanning electron microscope (SEM) is a type of electron microscope that images the sample surface by scanning it with a high-energy beam of electrons in a raster scan pattern. The electrons interact with the atoms that make up the sample producing signals that contain information about the sample's surface topography, composition and other properties such as electrical conductivity [18].

Figure 15: Scanning Electron Microscope

3.3 Sample Size and Related Parameter For Each Metallic Materials

3.3.1 Specimen Size for Taber Rotary Abraser

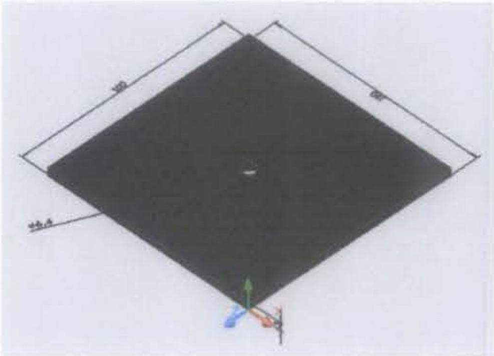


Figure 16: Sample for Taber Rotary Abraser

- Specimen: 100mm X 100mm X 3mm with a 6.4mm centre hole [13]
- Wheel and Load: H10 or H18 Calibrade with 250g, 500g or 1000g load

3.3.2 Specimen Size for Taber® Linear Abraser [19]

- Specimen: 25mm X 50mm X 2.5mm
- Wheel and Load: H10 or H18 Calibrade with 25.4mm stroke length and 2.54 mm/sec maximum velocity with 250g, 500g or 750g load

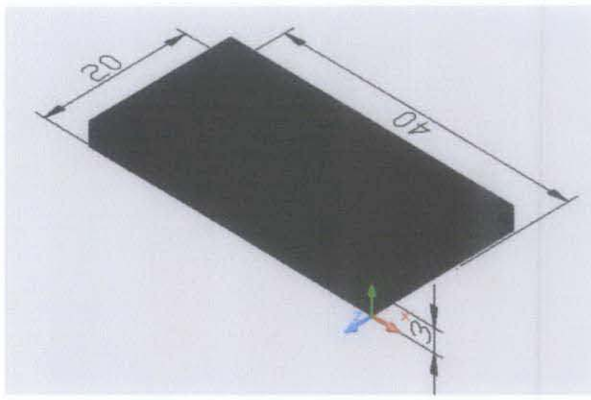


Figure 17: Sample for Taber Linear Abraser

3.3 Experiments - Procedure

Taber Rotary Abraser

1. Provided the specimen is flat, the surface profile and hardness of the samples is taken first.
2. A simple test for evaluating its abrasion or wear resistance is the Taber Abraser or Taber Abrader.
3. The test piece is secured to the instrument platform, which is motor driven at a fixed speed.
4. Two abrasive wheels are lowered onto the specimen surface, and as the platform rotates, it turns the two wheels. This causes a rub-wear action (sliding rotation) on the surface of the test-piece and the resulting abrasion marks form a pattern of crossed arcs in a circular band that cover an area of 30 cm2 against all angles of weave or grain.
5. For each round of testing, the specimen is weight and the data is recorded appropriately. A vacuum system removes debris during testing.
6. The specimen surface profile been measured at the last of the procedure. The step 1 till 5 is repeated for three times.

7. The grit feeder is attached to the Taber Rotary Abraser. Then, the experiment is repeated for three body experiment.

Taber Linear Abraser

1. The surface profile and hardness of the samples is taken accordingly.
2. The test piece then is clamped to the instrument platform.
3. Then, the pin abrader is lowered on the specimen surface, and its pin abrader moves linearly forward and backward. This will trigger rub-wear on the specimen surface and resulting abrasion marks form a pattern in a straight line.
4. For each round of testing, the specimen is weight and the data is tabulated accordingly.
5. The specimen surface profile been measured at the last of the procedure. The step 2-4 is repeated for three times for accuracy purposes.

3.5 Evaluation Method [19]

Equipment	Weight Lost Method	Volume Lost Method
Taber Rotary Abraser	Not applicable	$\frac{\text{Weight Loss X 1000 cycles}}{\text{Sp gravity specimen X Cycle Test}}$ = Taber Wear Index
Taber Linear Abraser	Weight Loss = W_b - W_a W_b-weight before W_a- Weight after	Volume loss = $\frac{\text{Weight Loss}}{\text{Specimen gravity}}$

Table 1: Table for Evaluation Method

Chapter 4

RESULT AND DISCUSSION

4.0 Result

4.1.0 Sample Roughness (Refer to Appendix 1-A and 1-B)

Sample/Arithmetic Roughness	$R_{a,\ initial}$ (µm)	$R_{a,\ after}$(µm)	$R_{a,\ different}$(µm)
Aluminum 6064	0.197	1.147	0.950
Mild Steel	0.507	1.260	0.753
Stainless Steel 316	0.193	0.683	0.490

Sample/Mean Roughness Depth	$R_{z,\ initial}$ (µm)	$R_{z,\ after}$(µm)	$R_{z,\ different}$(µm)
Aluminum 6064	1.840	7.268	5.428
Mild Steel	3.740	10.397	6.657
Stainless Steel 316	1.623	5.080	3.457

Table 2: Table of Surface Profile for Taber Abraser Linear

Sample/Arithmetic Roughness	$R_{a,\ initial}$ (µm)	$R_{a,\ after}$(µm)	$R_{a,\ different}$(µm)
Aluminum 6064	0.677	3.537	2.860
Mild Steel	0.433	1.320	0.887
Stainless Steel 316	0.217	0.730	0.513

Sample/Mean Roughness Depth	$R_{z,\ initial}$ (µm)	$R_{z,\ after}$(µm)	$R_{z,\ different}$(µm)
Aluminum 6064	5.403	18.963	13.560
Mild Steel	2.887	8.047	5.160
Stainless Steel 316	2.317	5.210	2.893

Table 3: Table of Surface Profile for Taber Abraser Rotary Two Body

Sample/Arithmetic Roughness	$R_{a,\ initial}$ (µm)	$R_{a,\ after}$(µm)	$R_{a,\ different}$(µm)
Aluminum 6064	0.277	2.447	2.170
Mild Steel	0.857	1.453	0.596
Stainless Steel 316	0.250	0.640	0.390

Sample/Mean Roughness Depth	$R_{z,\ initial}$ (µm)	$R_{z,\ after}$(µm)	$R_{z,\ different}$(µm)
Aluminum 6064	2.537	13.020	10.483
Mild Steel	5.753	10.360	4.607
Stainless Steel 316	2.737	4.960	2.223

Table 4: Table of Surface Profile for Taber Abraser Rotary Three Body

4.1.1 Sample Hardness (Hardness Rockwell scale F - HR(F))

Sample/Arithmetic Roughness	$Hardness_{average, initial}$	$Hardness_{average, final}$	Δ Hardness (HR(F))
Aluminum 6064	78.43	74.60	3.83
Mild Steel	98.63	95.77	2.87
Stainless Steel 316	110.70	108.93	1.77

Table 5: Table of Hardness for Taber Linear Abraser

Sample/Arithmetic Roughness	$Hardness_{average, initial}$	$Hardness_{average, final}$	Δ Hardness (HR(F))
Aluminum 6064	75.43	70.57	4.87
Mild Steel	98.63	94.27	4.37
Stainless Steel 316	106.23	104.67	1.57

Table 6: Table of Hardness for Taber Rotary Abraser Two Body

Sample/Arithmetic Roughness	$Hardness_{average, initial}$	$Hardness_{average, final}$	Δ Hardness (HR(F))
Aluminum 6064	75.13	70.93	4.20
Mild Steel	98.60	95.07	3.53
Stainless Steel 316	105.97	104.97	1.00

Table 7: Table of Hardness for Taber Rotary Abraser Three Body

4.2. Taber Linear Abraser

4.2.1 Taber Linear Abraser for 250g Load

Cycle/Metal	Stainless Steel 316	Aluminum 6063	Mild Steel
50	1.33	2.33	3.67
100	2.67	4.33	6.67
150	3.67	5.67	9.33
200	4.67	6.67	11.00
250	6.00	8. 00	13.33
300	7.67	9.67	15.67

Table 8: Table of Weight Loss (mg) for Taber Linear Abraser for 250g Load

Cycle/Metal	Stainless Steel 316	Aluminum 6063	Mild Steel
50	0.17	1.23	0.64
100	0.34	1.60	0.85
150	0.46	2.14	1.19
200	0.60	2.56	1.40
250	0.75	2.98	1.49
300	0.96	3.57	1.70

Table 9: Table of Volume Loss for Taber Linear Abraser for 250g Load

Figure 17: Graph for Weight Loss of Taber Linear for 250g Load

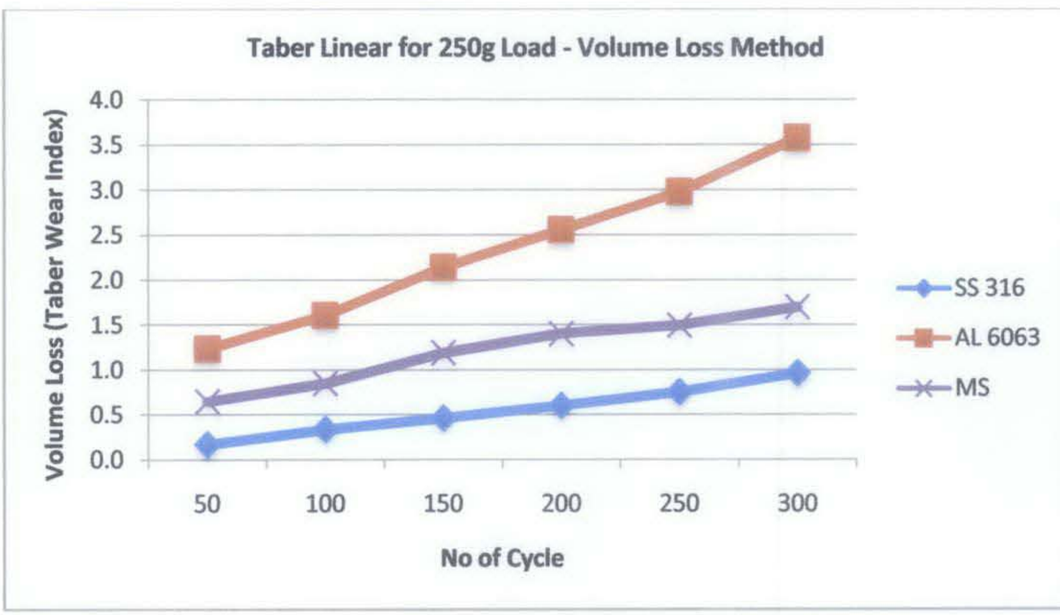


Figure 18: Graph for Volume Loss Method of Taber Linear for 250g Load

4.2.2 Taber Linear Abraser for 500g Load

Cycle/Metal	Stainless Steel 316	Aluminum 6063	Mild Steel
50	2.67	3.33	4.33
100	3.67	5.00	8.33
150	4.67	6.33	12.00
200	6.00	8.00	14.33
250	7.33	9.33	16.67
300	9. 00	11.67	19.33

Table 10: Table of Weight Loss (mg) Method for Taber Linear Abraser for 500g Load

Cycle/Metal	Stainless Steel 316	Aluminum 6063	Mild Steel
50	0.31	1.21	0.67
100	0.46	1.85	1.06
150	0.59	2.34	1.53
200	0.75	2.96	1.93
250	0.93	3.46	2.22
300	1.14	4.32	2.46

Table 11: Table of Volume Loss Method for Taber Linear Abraser for 500g Load

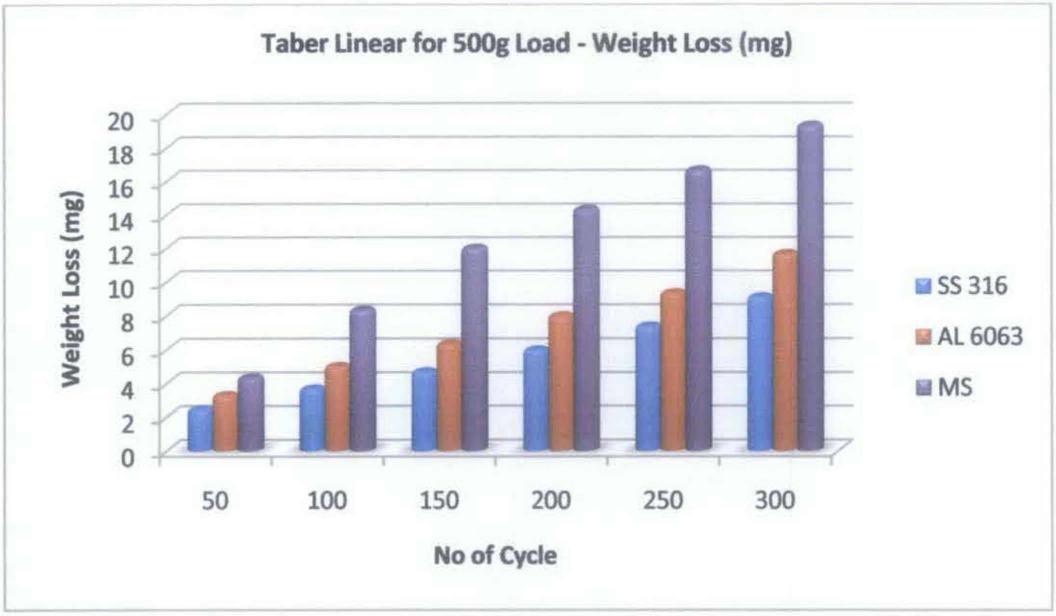


Figure 19: Graph for Weight Loss of Taber Linear for 500g Load

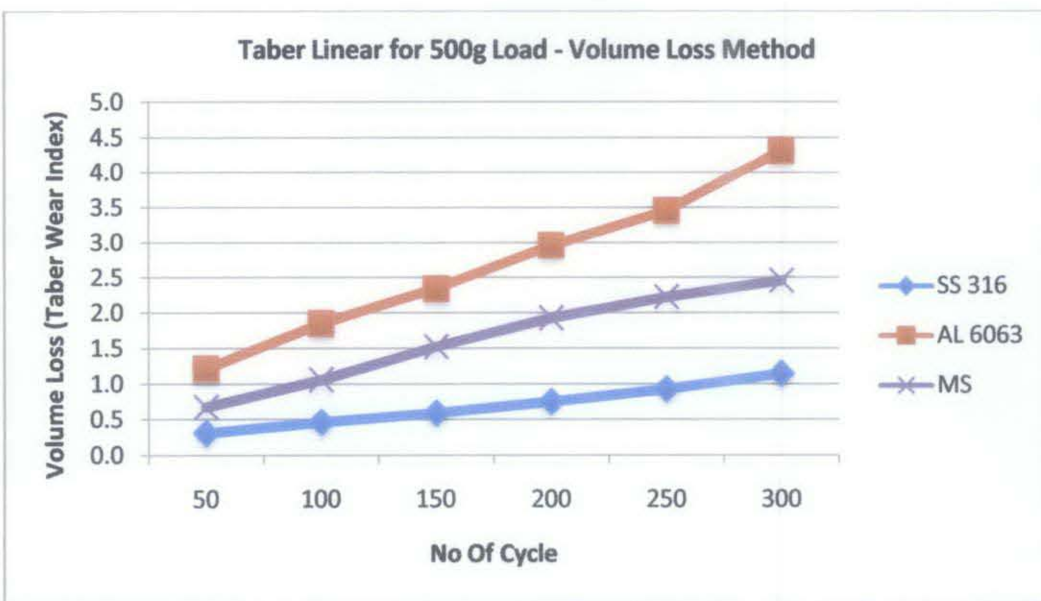


Figure 20: Graph for Volume Loss of Taber Linear for 500g Load

4.2.3 Taber Linear Abraser for 750g Load

Cycle/Metal	Stainlee Steel 316	Aluminum 6063	Mild Steel
50	3.10	4.50	5.33
100	4.63	6.67	11.00
150	5.66	7.67	14.00
200	7. 00	9. 00	17.67
250	8.33	10. 00	22.00
300	10.00	11.67	24.67

Table 12: Table of Weight Loss (mg) for Taber Linear Abraser for 750g Load

Cycle/Metal	Stainless Steel 316	Aluminum 6063	Mild Steel
50	0.39	1.67	0.93
100	0.58	2.47	1.39
150	0.72	2.96	1.78
200	0.91	3.37	2.25
250	1.06	3.78	2.79
300	1.23	4.43	3.13

Table 13: Table of Volume Loss Method for Taber Linear Abraser for 750g Load

Figure 21: Graph for Weight Loss of Taber Linear for 750g Load

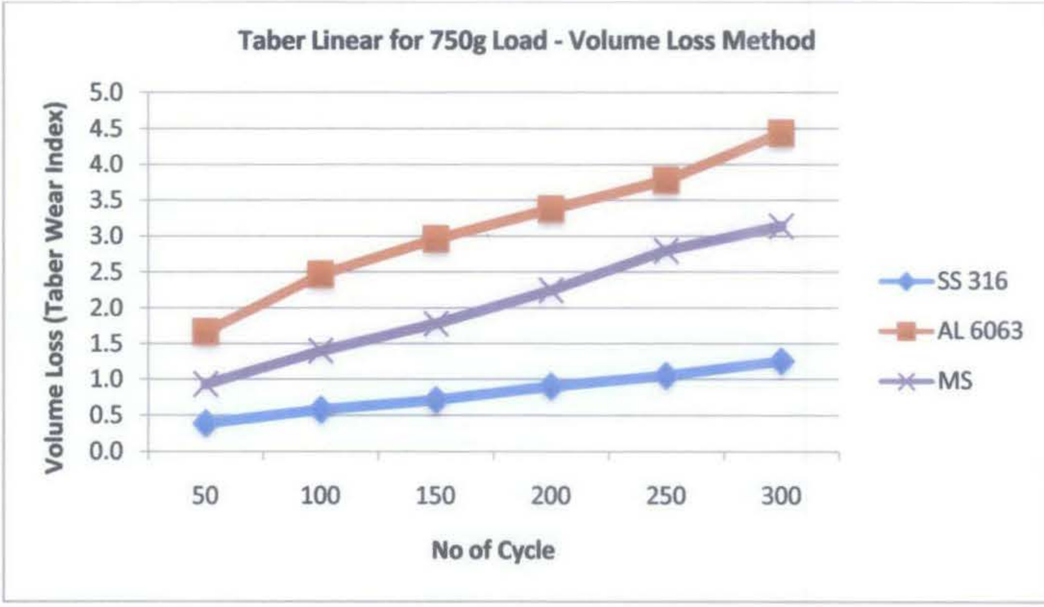


Figure 22: Graph for Volume Loss Method of Taber Linear for 750g Load

4.3 Taber Rotary Abraser for Two Body Mechanism

4.3.1 Taber Rotary Abraser for 250g Load

Cycle/Metal	Stainless Steel 316	Aluminum 6063	Mild Steel
50	4.00	6.50	26.67
100	9.67	12.33	29.67
150	16.33	21.00	47.00
200	21.00	30.00	62.33
250	27.00	41.33	77.67
300	32.00	53. 00	83.00

Table 14: Table of Weight Loss (mg) for Taber Rotary Abraser for 250g Load

Cycle/Metal	Stainless Steel 316	Aluminum 6063	Mild Steel
50	14.02	45.70	35.24
100	14.24	48.15	37.23
150	14.53	51.99	38.19
200	15.04	55.59	39.70
250	15.86	61.08	40.16
300	16.94	65.58	42.04

Table 15: Table of Volume Loss Method for Taber Rotary Abraser for 250g

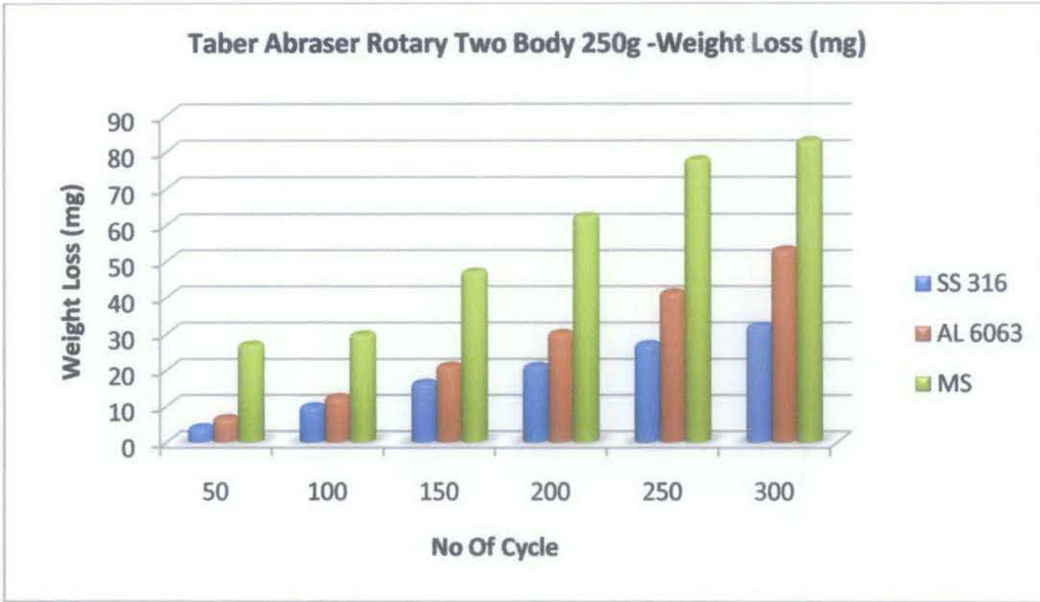


Figure 23: Graph for Weight Loss of Taber Rotary for 250g Load

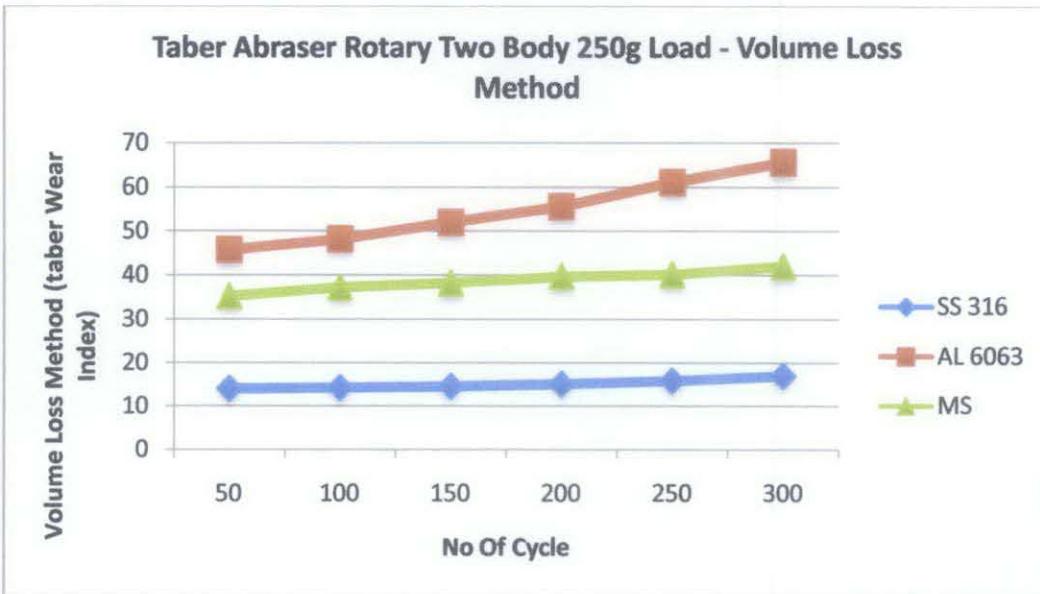


Figure 24: Graph for Volume Loss Method of Taber Rotary for 250g Load

4.3.2 Taber Rotary Abraser for 500g Load

Cycle/Metal	Stainless Steel 316	Aluminum 6063	Mild Steel
50	5.67	12.80	15.67
100	11.67	19.90	30.67
150	18.67	27.67	47.33
200	26.67	40.00	61.67
250	32.61	53.33	76.00
300	42.00	66.00	84.33

Table 16: Table of Weight Loss (mg) for Taber Rotary Abraser for 500g

Cycle/Metal	Stainless Steel 316	Aluminum 6063	Mild Steel
50	14.26	60.39	50.12
100	16.74	65.93	52.398
150	17.37	71.43	53.92
200	18.36	77.27	56.01
250	19.35	81.23	57.37
300	20.84	85.27	58.37

Table 17: Table of Volume Loss Method for Taber Rotary Abraser for 500g

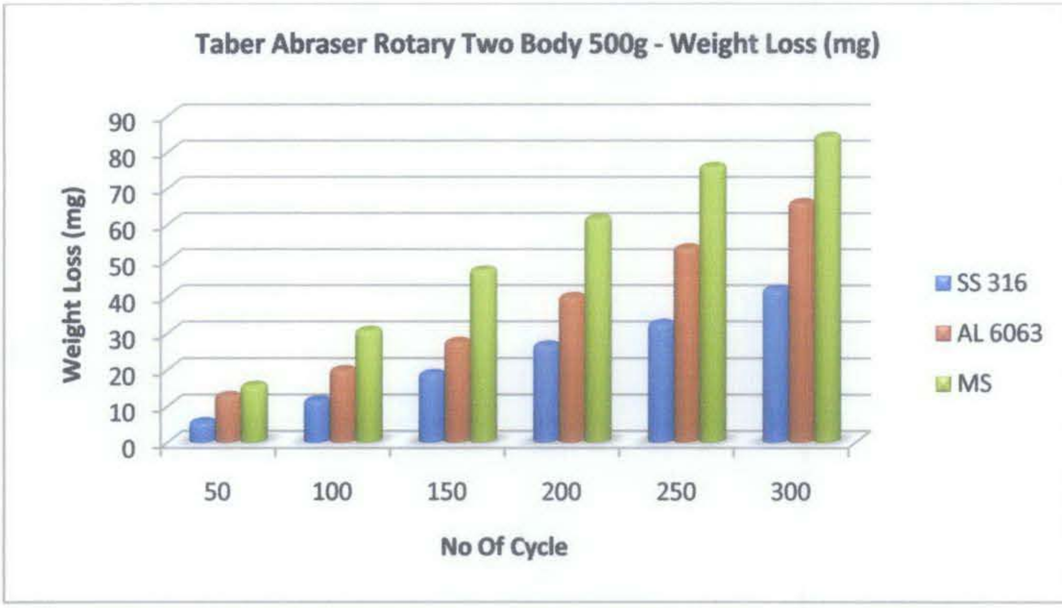


Figure 25: Graph for Weight Loss of Taber Rotary for 500g Load

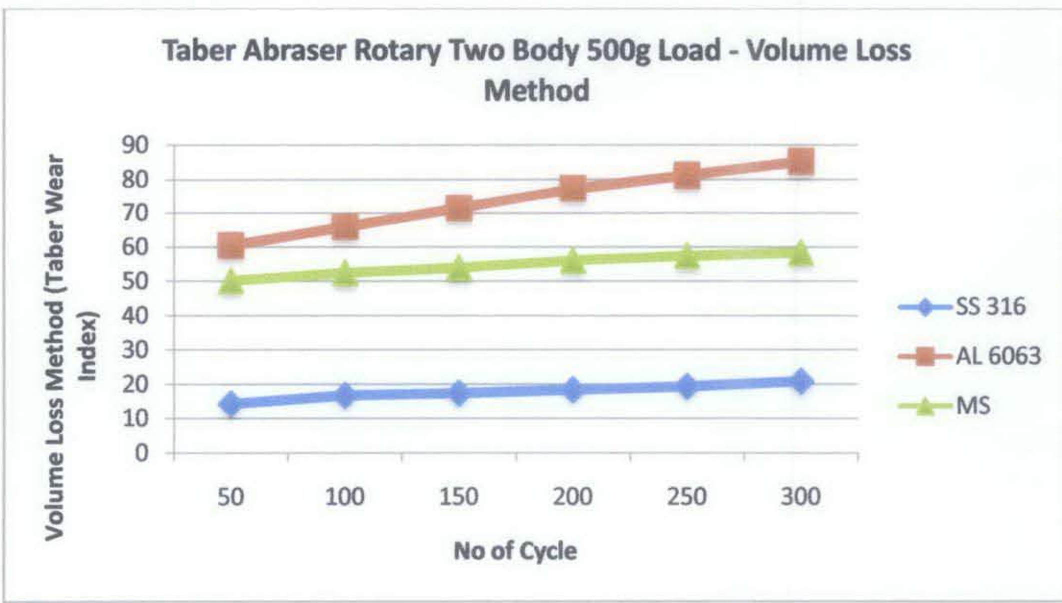


Figure 26: Graph for Volume Loss Method of Taber Rotary for 500g Load

4.3.3 Taber Rotary Abraser for 1000g Load

Cycle/Metal	Stainless Steel 316	Aluminum 6063	Mild Steel
50	10.67	18.33	29.33
100	20.00	31.00	58.67
150	30.00	41.67	71.00
200	38.67	51.02	110.00
250	47.33	65.34	125.33
300	56.00	74.36	164.33

Table 18: Table of Weight Loss (mg) for Taber Rotary Abraser for 1000g

Cycle/Metal	Stainless Steel 316	Aluminum 6063	Mild Steel
50	23.48	91.80	63.92
100	23.82	98.64	65.93
150	24.32	107.40	70.12
200	24.82	111.24	73.12
250	26.16	117.38	75.92
300	28.84	126.49	78.23

Table 19: Table of Volume Loss Method for Taber Rotary Abraser for 1000g

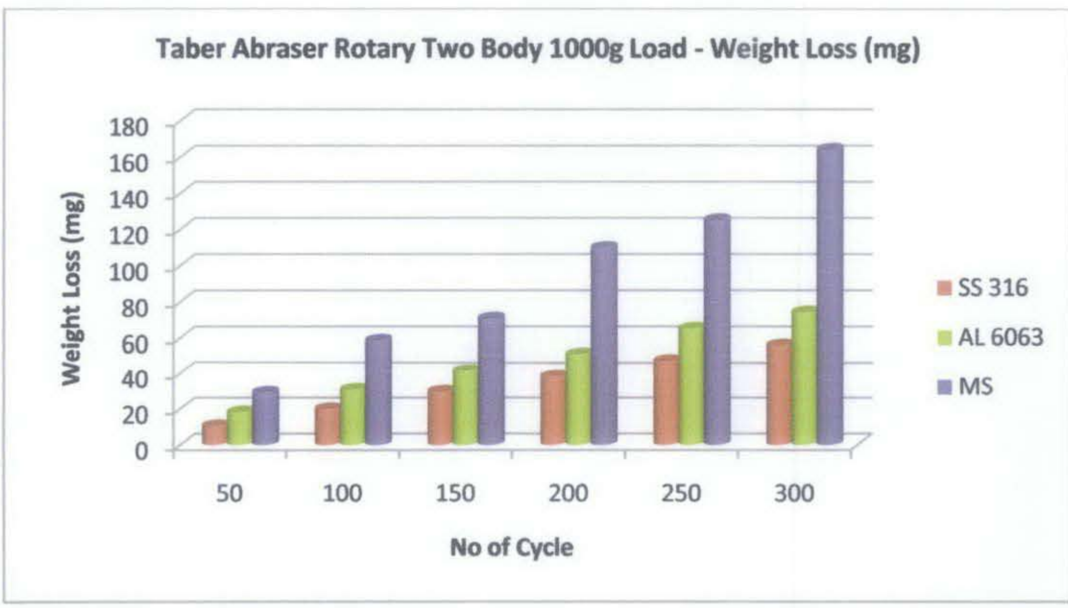


Figure 27: Graph for Weight Loss of Taber Rotary for 1000g Load

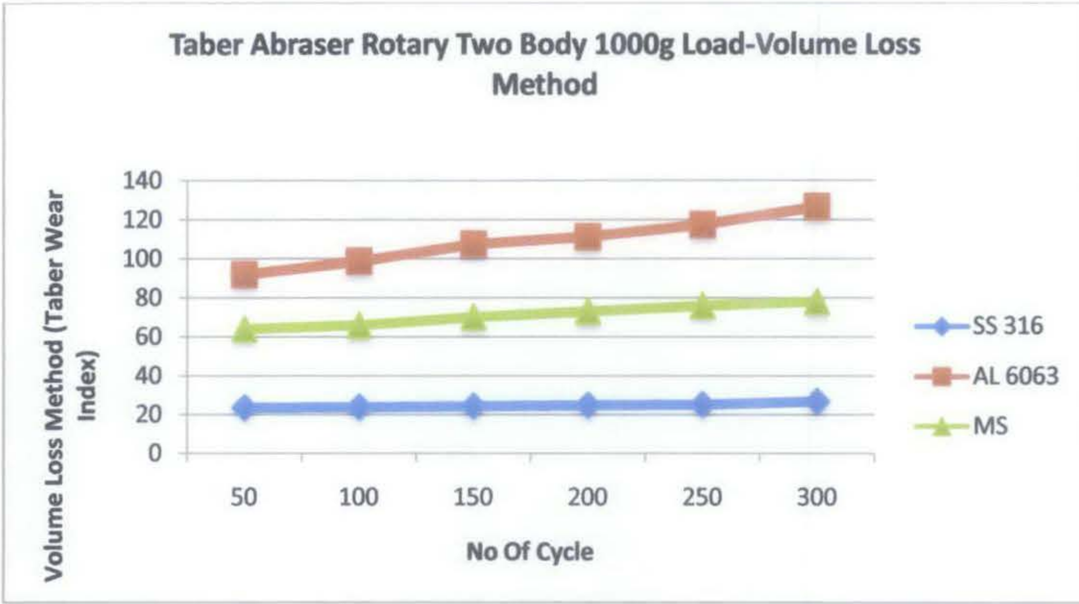


Figure 28: Graph for Volume Loss Method of Taber Rotary for 1000g Load

4.4 Taber Rotary Abraser for Three Body Mechanism

4.4.1 Taber Rotary Abraser for 250g Load

Cycle/Metal	Stainless Steel 316	Aluminum 6063	Mild Steel
50	5.33	9.67	15.00
100	6.67	11.67	31.00
150	8.67	13.67	43.67
200	10.00	17.00	50.67
250	12.67	21.67	64.67
300	15.33	24.00	65.67

Table 20: Table of Weight Loss (mg) for Taber Rotary Abraser for 250g

Cycle/Metal	Stainless Steel 316	Aluminum 6063	Mild Steel
50	13.42	30.92	26.39
100	14.02	33.91	27.99
150	14.59	36.93	29.28
200	14.88	39.92	31.39
250	15.52	43.21	33.38
300	16.32	47.33	35.98

Table 21: Table of Volume Loss Method for Taber Rotary Abraser for 250g

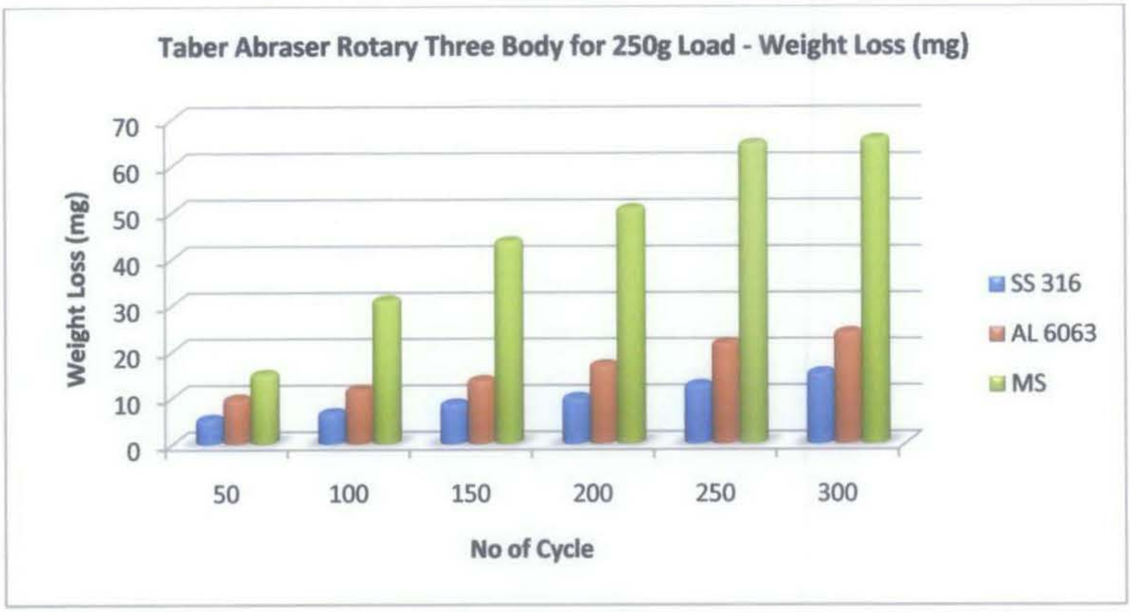


Figure 29: Graph for Weight Loss of Taber Linear for 250g Load

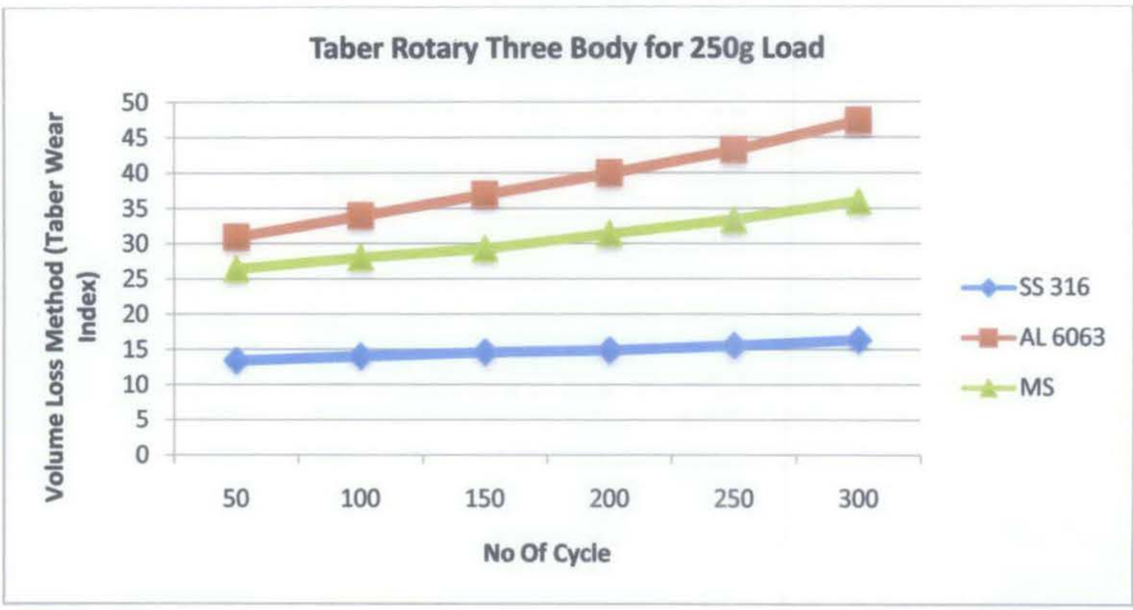


Figure 30: Graph for Volume Loss Method of Taber Rotary for 250g Load

4.4.2 Taber Rotary Abraser for 500g Load

Cycle/Metal	Stainless Steel 316	Aluminum 6063	Mild Steel
50	7.67	10.33	15.00
100	13.00	13.67	31.00
150	15.67	18.33	45.33
200	20.67	22.33	51.67
250	24.67	28.67	69.00
300	25.67	33.33	86.33

Table 22: Table of Weight Loss (mg) for Taber Rotary Abraser for 500g

Cycle/Metal	Stainless Steel 316	Aluminum 6063	Mild Steel
50	14.04	37.29	32.91
100	14.48	39.93	34.35
150	14.99	42.29	35.32
200	15.92	45.93	37.25
250	16.97	49.21	38.50
300	17.92	52.20	39.72

Table 23: Table of Volume Loss Method for Taber Rotary Abraser for 500g

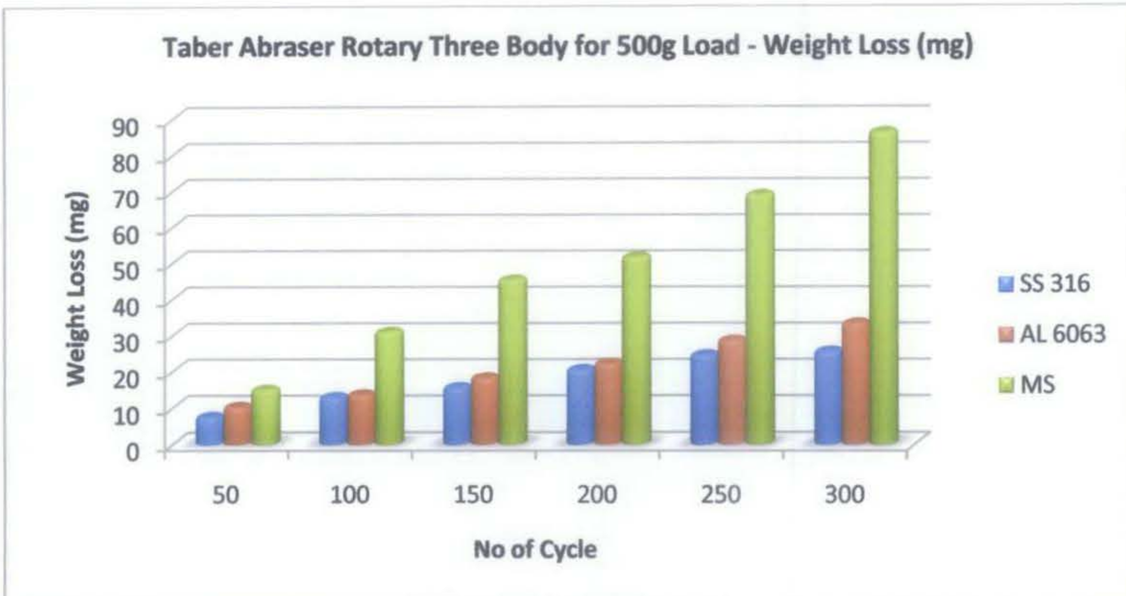


Figure 31: Graph for Weight Loss of Taber Linear for 500g Load

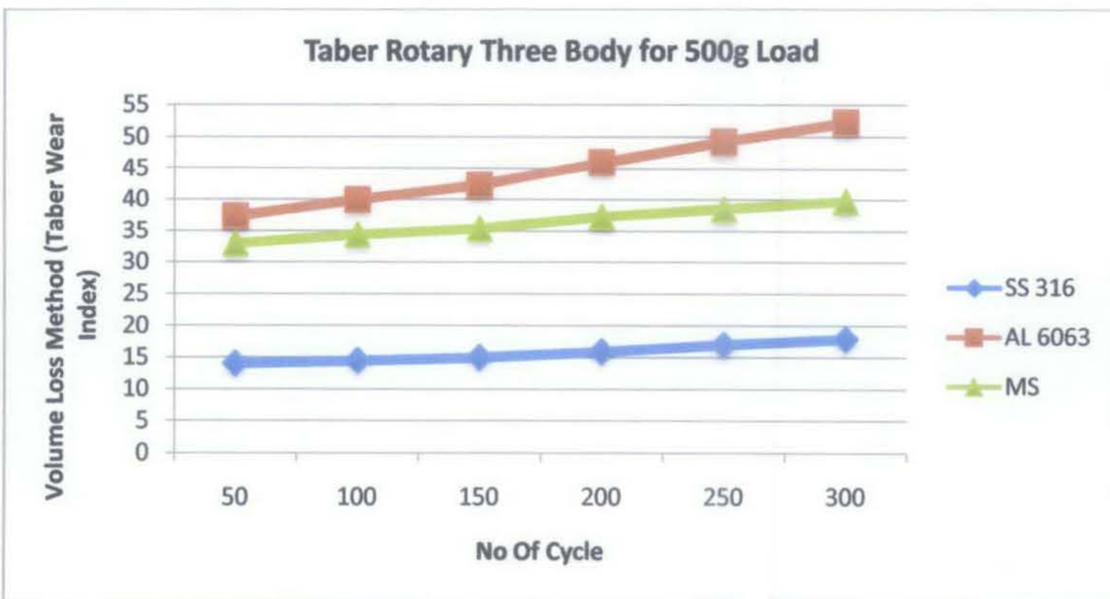


Figure 32: Graph for Volume Loss Method of Taber Rotary for 500g Load

4.4.3 Taber Rotary Abraser for 1000g Load

Cycle/Metal	Stainless Steel 316	Aluminum 6063	Mild Steel
50	11.00	18.00	27.33
100	20.33	24.33	50.00
150	27.67	34.67	79.33
200	38.67	42.67	102.67
250	46.33	50.67	113.00
300	49.67	54.00	140.67

Table 24: Table of Weight Loss (mg) for Taber Rotary Abraser for 1000g

Cycle/Metal	Stainless Steel 316	Aluminum 6063	Mild Steel
50	20.82	69.39	57.57
100	22.19	75.12	59.73
150	24.31	84.12	63.03
200	24.83	93.19	65.39
250	25.49	104.18	68.39
300	26.49	115.32	71.92

Table 25: Table of Volume Loss Method for Taber Rotary Abraser for 1000g

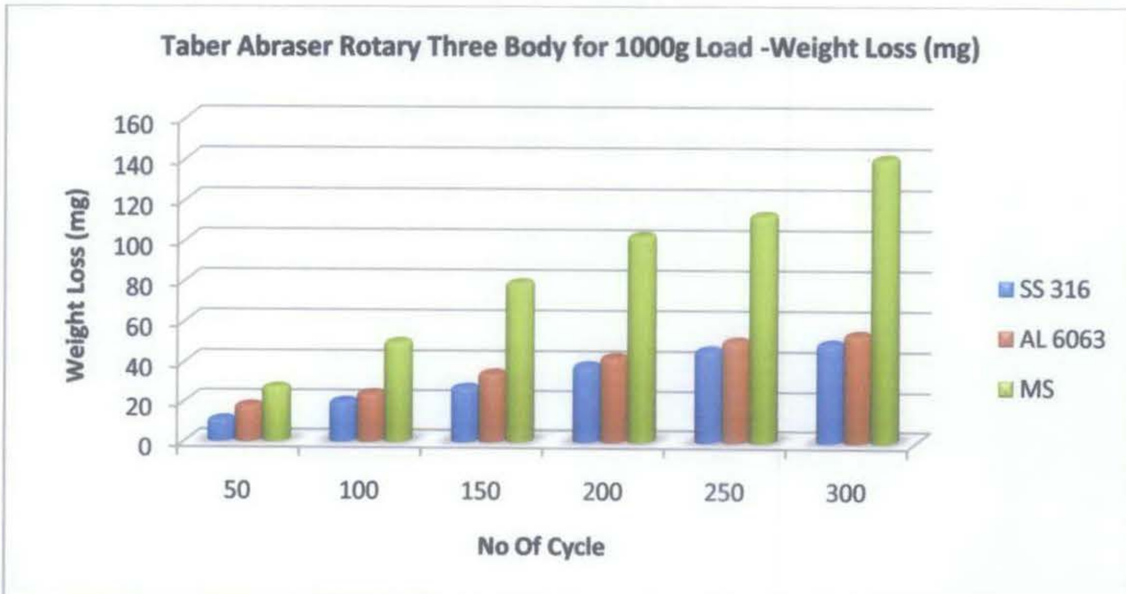


Figure 33: Graph for Weight Loss of Taber Linear for 1000g Load

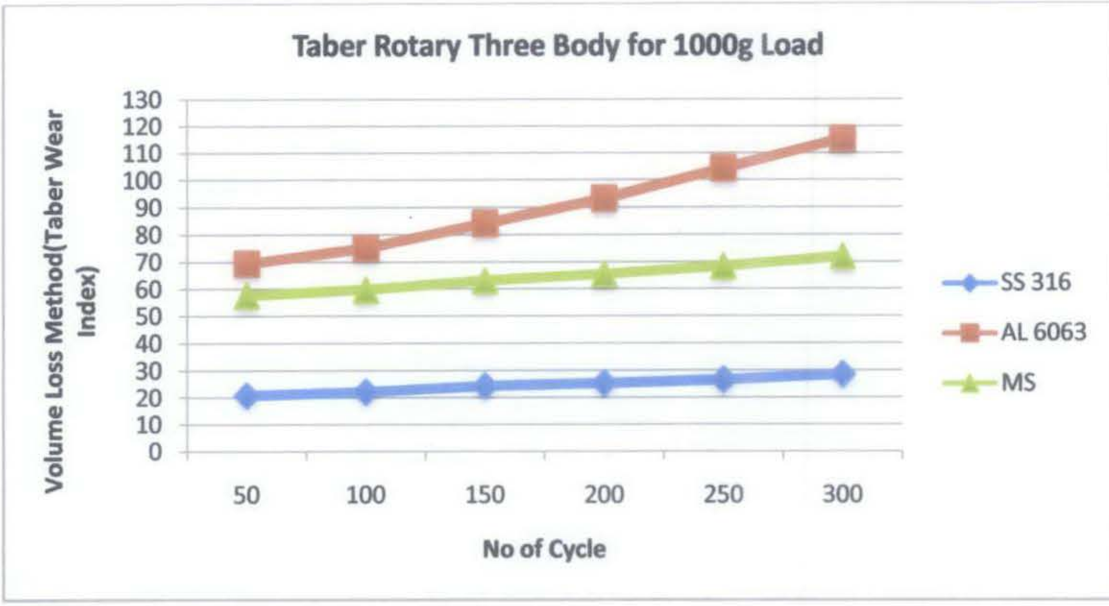


Figure 34: Graph for Volume Loss Method of Taber Rotary for 1000g Load

4.5 Discussion

Weight loss would generate a non-dimensional wear of Taber Wear Index using the given formula. The theoretical wear characteristic is obtained by calculating the wear based on Volume Loss Method for Aluminum 6063, Stainless Steel 316 and Mild Steel for the given number of cycles versus the weight loss and the non-dimensional, Taber Wear Index of abrasion wear.

4.5.1 Taber Linear Abraser

Using the Taber Linear Abraser, the abrader is in the different shape and size which looks like a pencil eraser. Once it moving backward and forward linearly in a straight line, the samples were scratched. The wear rate is determined by evaluating weight loss and Volume Loss Method (Taber Wear Index) methods on the grooves of the wear scratches.

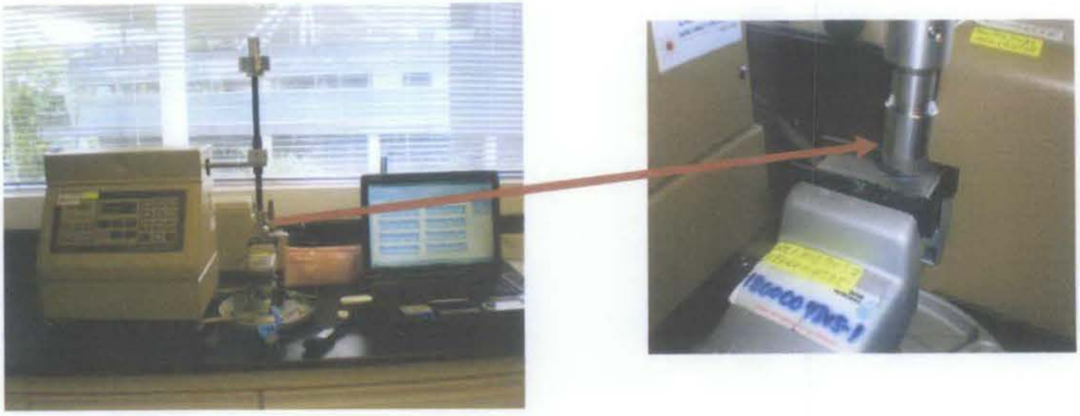


Figure 35 : Taber Linear Abraser

Burwell and Strang[10] concluded that wear rate is proportional to the load and independent of pressure unless the area of contact was equivalent to one-third of the materials' hardness. For Taber Linear Abraser, the Volume Loss Method only uses the formula by dividing the total weight loss to its density (Table 3). Based on the Table 8, 9, 10, 11, 12, 13 and Figure 17, 18, 19, 20, 21, 22, the increasing linearly-pattern of graph for Weight Loss and Volume Loss can be observed clearly. For Aluminum 6063, the Volume Loss is higher compared to Stainless Steel 316 especially for 750g loads and 300 cycles which cause 4.43 Taber Wear Index for Aluminum 6063 and 1.26 Taber Wear Index for Stainless Steel 316. Even though the Mild Steel experienced the higher weight loss compared to the other, the correction factor, which is density corrected the true value of Taber Wear Index.

The surface roughness, R_a is calculated by an algorithm that measures the average length between the peaks and valleys and the deviation from the mean line on the entire surface within the sampling length. R_a averages all peaks and valleys of the roughness profile and then neutralizes the few outlying points so that the extreme points have no significant impact on the final results [18]. For the surface profile change, R_a, aluminum experienced 0.91 μm changes compared to Stainless Steel 316 0.49 μm as shown in Table 2. Based on Table 2, Mild Steel experienced R_a of 0.86 μm changes.

Stainless Steel 316 has the higher hardness reading compared to aluminum which is 110.7 HR(F) and Aluminum 6063 is 78.4 as stated in Table 5. In the other hand, the hardness for Mild Steel is 98.6 HR(F). Aluminum 6063 experienced the higher amount of hardness change which is 3.83 HR(F) and Stainless Steel 316 experienced the least amount of hardness change, 1.77 HR(F). This means the Stainless Steel 316 wear rate is slower compared to the others as this fact will determine that Stainless Steel 316 have higher abrasive resistance compared to Aluminum 6063, and Mild Steel, which mostly influenced by its hardness. Figure 36 shows the difference of the sample before and after the test.

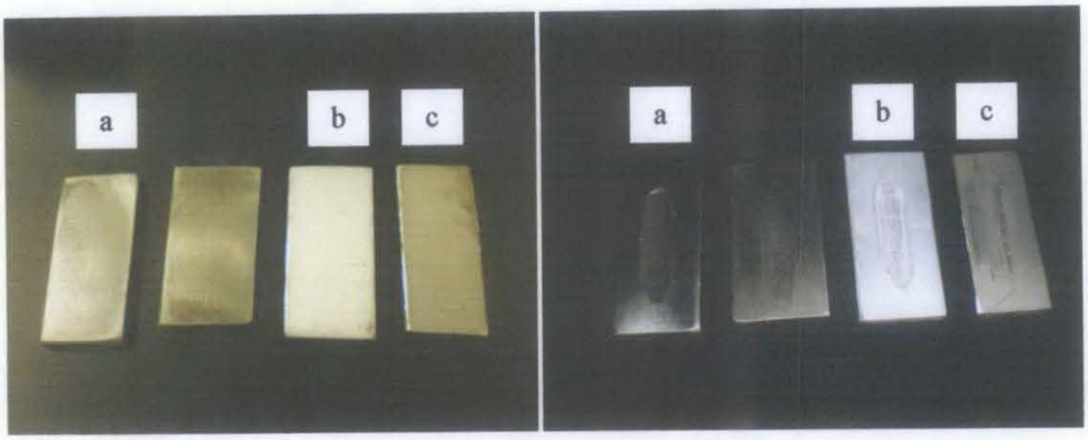


Figure 36: Sample before and after the testing for Taber Linear – a) Mild Steel b) Aluminum 6963, c) Stainless Steel 316

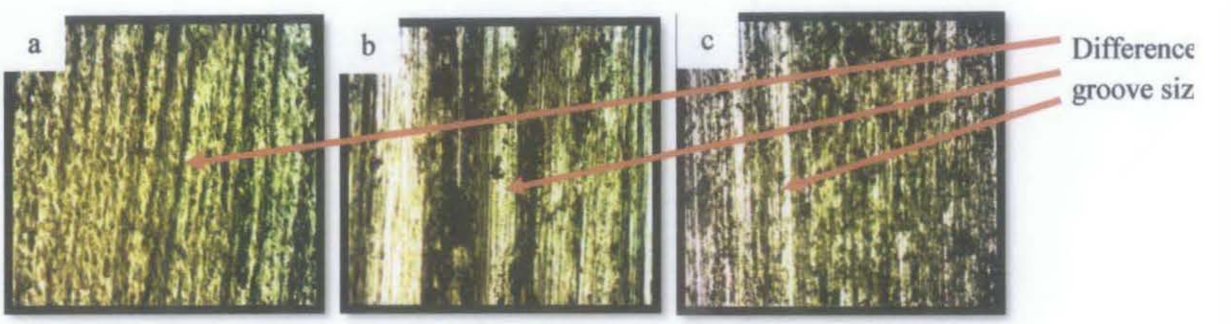


Figure 37: Sample after abrasion testing visualize using Optical Microscope - a) Mild Steel b) Aluminum 6063, c) Stainless Steel 316

Figure 37 a), b) and c) shown that Aluminum 6063 had a deeper groove compare to Stainless steel 316 and Mild Steel. It means that Aluminum is more affected and having more weight loss compared to the other materials. As this will prove that, Aluminum 6063 has lower abrasive resistivity and higher Taber Wear Index value.

4.5.2 Taber Rotary Abraser – 2 Body Abrasion

Under the low stress condition, the abrader H-10 sliding against a metal surface cause scratches or microcuts, forming slivers or small chips as lost materials. Since only two bodies (abrader and sample) are involved, this type of wear is also known as two body abrasion. This type of two body abrasive wear, with low velocities and low stress, occurs in earthmoving equipment, agricultural implements, classifier, screens and augers. High velocity low stress two body abrasion occurs in slurry pump, nozzles, cyclone, and sand slinger.

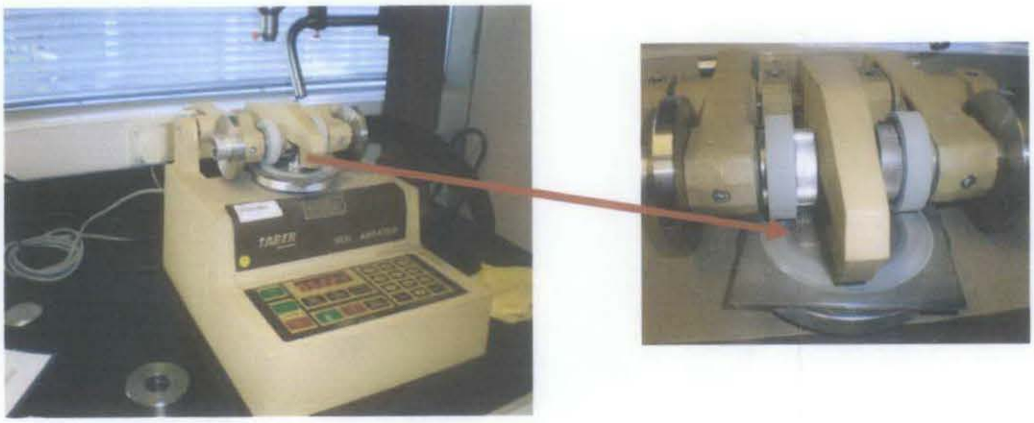


Figure 38 : Taber Rotary Abraser

The abrasion resistance of a material can be evaluated through its Volume Loss Method. For Taber Wear index (rate of wear) is the loss in weight in milligrams per thousand cycles of abrasion for a test performed under a specific set of conditions. The lower the wear index, the better the abrasion resistance of the material [19]. In Volume Loss Method, the result obtained is been corrected using specific gravity of the specimen. A correction for the specific gravity of each material should be applied to the weight loss to give measure of the comparative wear resistance [19]. The use of this correction factor gives a wear index related to the loss in volume for the material to which it applied. Using the specific gravity for Stainless Steel 316 as 7.95, the specific gravity for Aluminum 6063 as 2.7 and Mild Steel as 7.86, the Volume Loss is calculated. Pattern of the graph can be seen in Figure 23, 24, 25, 26, 27, 28 that Aluminum has the highest value of Taber Wear Index. Under 1000g load and 300 cycles, Aluminum 6063 experienced much greater volume loss which is 126.49 Taber Wear Index compared to Stainless Steel 316, 26.834 Taber Wear Index as shown in Table 14, 15, 16, 17, 18, 19. After the calculation Mild Steel Taber Wear Index is only 78.23. So, this method also agreed that Stainless Steel 316 has higher abrasive resistivity compared to Aluminum 6063.

In this experiment, it been witnessed that abrasive wear will give impact on surface roughness. The higher the abrasive wear rate, the higher the change in surface roughness will be. It is proven when Aluminum 6063 has 2.8660 μm of surface roughness changes compared to Stainless Steel 316, which has only 0.513μm surface roughness and Mild Steel has 0.887 μm of surface roughness as shown in Table 3. The hardness also will affect the surface roughness after a material has experienced the abrasive wear conditions. The Stainless Steel 316 with higher hardness, 104.7 HR(F) has only changed around 1.567 HR(F), than the aluminum 6063, 4.867 HR(F) which has hardness of 75.4 on the scale of HR(F) and Mild Steel decrease its hardness about 4.267HR(F) from 98.6 as shown in Table 4. The wear rate of the components can be reduced by making them harder. The wear resistance of pure metals and annealed steels increases linearly with hardness. Figure 39 shows the samples after abrasive wear testing.

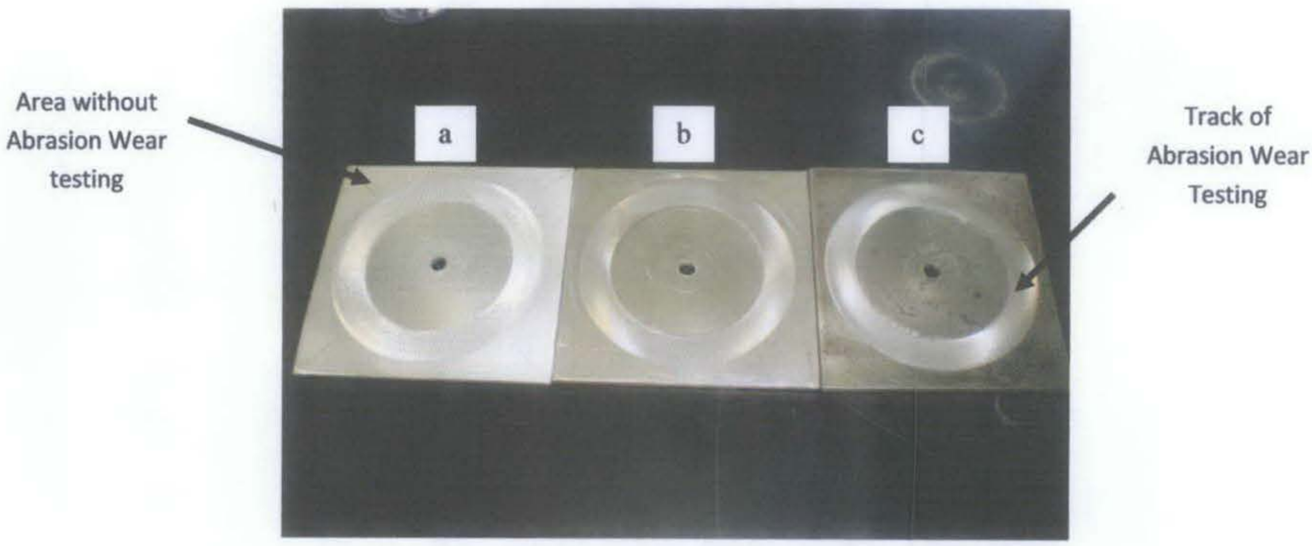


Figure 39: The Sample after Abrasion Wear Testing - a)Aluminum 6063, b) Stainless Steel 316, c) Mild Steel

Figure 40: Visualization of Aluminum 6063 after testing using SEM Mag =50X

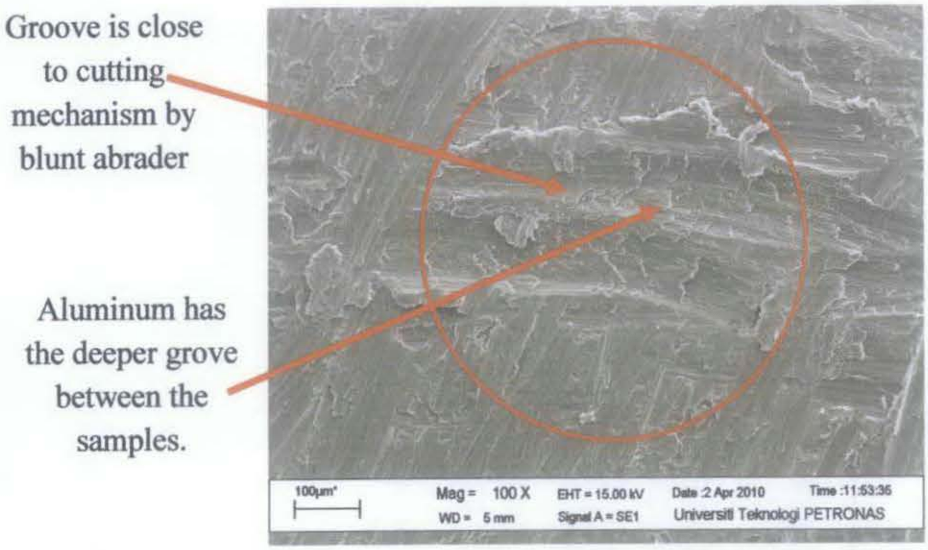


Figure 41: Visualization of Aluminum 6063 after testing using SEM Mag =100X

Figure 42: Visualization of Mild Steel after testing using SEM Mag =100X

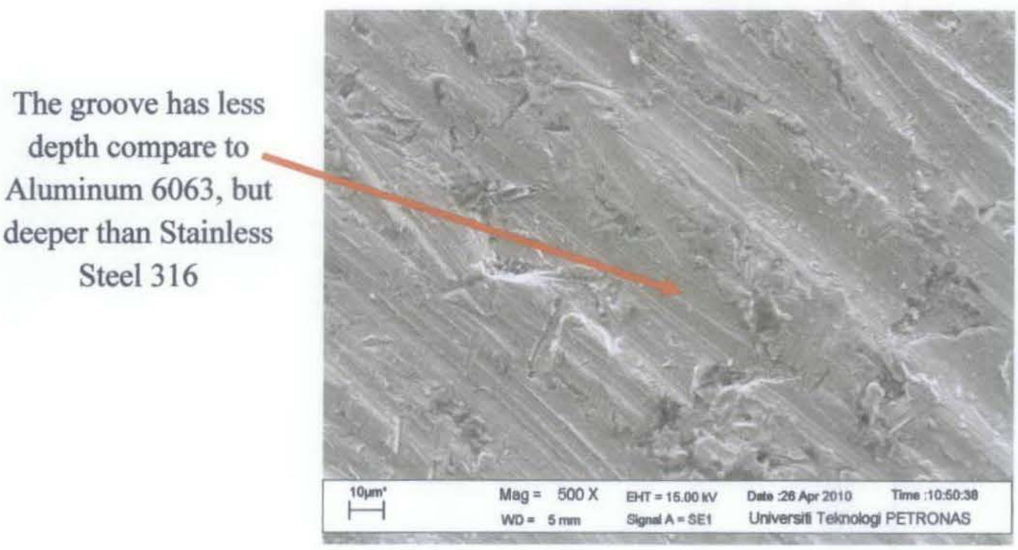


Figure 43: Visualization of Mild Steel after testing using SEM Mag =500X

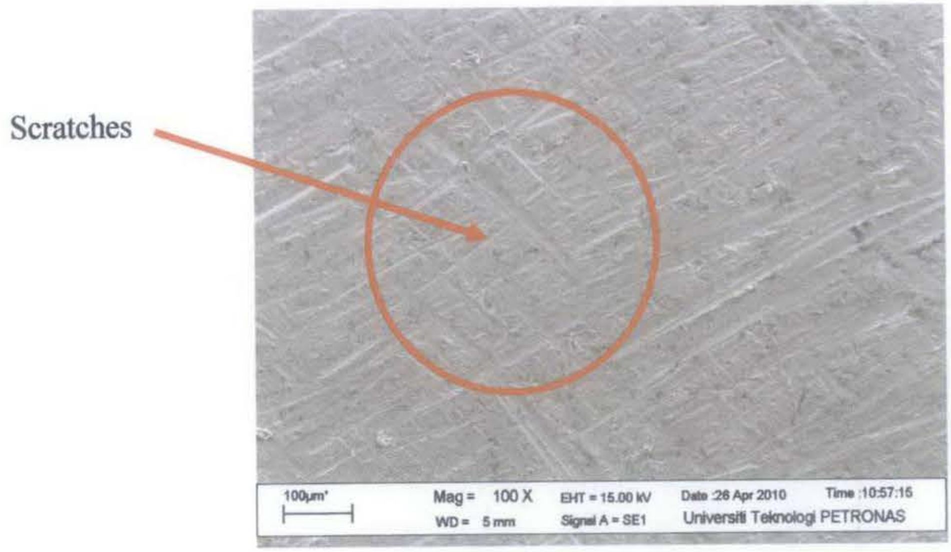


Figure 44: Visualization of Stainless Steel 316 after testing using SEM Mag =100X

Figure 45: Visualization of Stainless Steel 316 after testing using SEM Mag =500X

Based on Figure 40, 41, 42, 43, 44, and 45, the difference between the scratching patterns can be observed clearly. This mechanism of abrasive wear is called ploughing. It means that the wear is due to repeated abrasion by a blunt abrader that finally cause uneven and worn surface. The lower hardness material scratches easily and left deeper groove compared to a harder material. Due to the bigger and deeper grooves, it proved that Aluminum 6063 experienced higher weight loss and less resistibility to abrasion wear. In this case, it explains well on the scratching patterns of Aluminum 6063 compared to Stainless Steel 316 and Mild Steel.

4.5.3 Taber Rotary Abraser – 3 Body Abrasion

For three body abrasion, the testing involved three components which are the H-10 abrader, sample and the Aluminum Silicate grit with size of 240 meshes. The grit is introduced using the grit feeder attached to the Taber Rotary Abraser. The grit circulated in between of the abraser and the rotating sample.

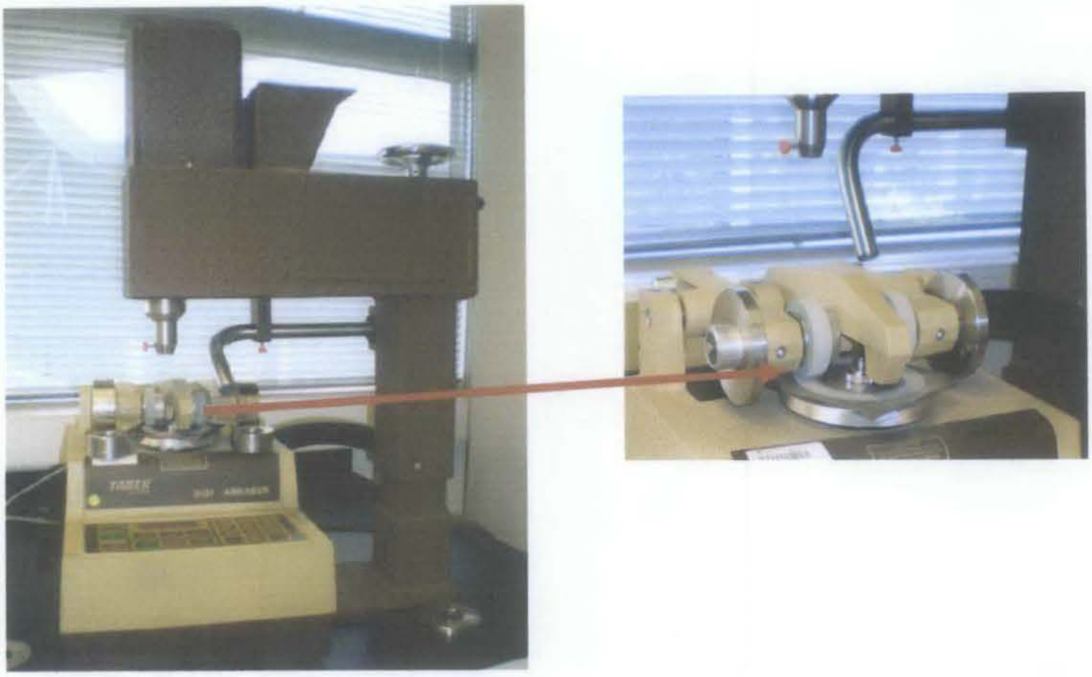


Figure 46 : Taber Rotary Abraser with Grit Feeder

The evaluation method for this three body abrasion is Volume Loss Method. All the weight loss is plugged into the formula and the results are corrected using specific gravity of the material. The data from Table 20, 21, 22, 23, 24, 25 and Figure 29, 30, 31, 32, 33, 34 shows the trend of a weight loss and Taber Wear Index for each sample. Under 1000g load and 300 cycles, Stainless Steel 316 loss 49.77mg weight, Mild Steel loss 71.92mg and Aluminum 6063 loss about 54.0mg. However after the calculation using Volume Loss Method, Stainless Steel value of Taber Wear Index is 28.49, Mild Steel is 71.92 and Aluminum is 115.33. The higher the number of Taber Wear Index means the lower ability of a material to resist abrasive wear effects.

After the testing, Stainless Steel have the least amount of surface profile change which is 0.390 μm. Aluminum 6063 experienced 2.17 μm and Mild Steel has 0.596 μm of surface profile change as shown in Table 4. So this proved the relation of surface profile change with its hardness. The surface roughness of a material is closely depending on the hardness of the sample. Hardness for Stainless Steel, 106 HR(F) only decreased 1 HR(F) after the testing. In the other hand, Aluminum 6063 reduced 4.4 HR(F) of its hardness from 75.1 HR(F) and Mild Steel reduced its hardness about 3.533 HR(F) from 98.6HR(F) as shown in Table 7. As the hardness increases, the surface profile change will be decrease.

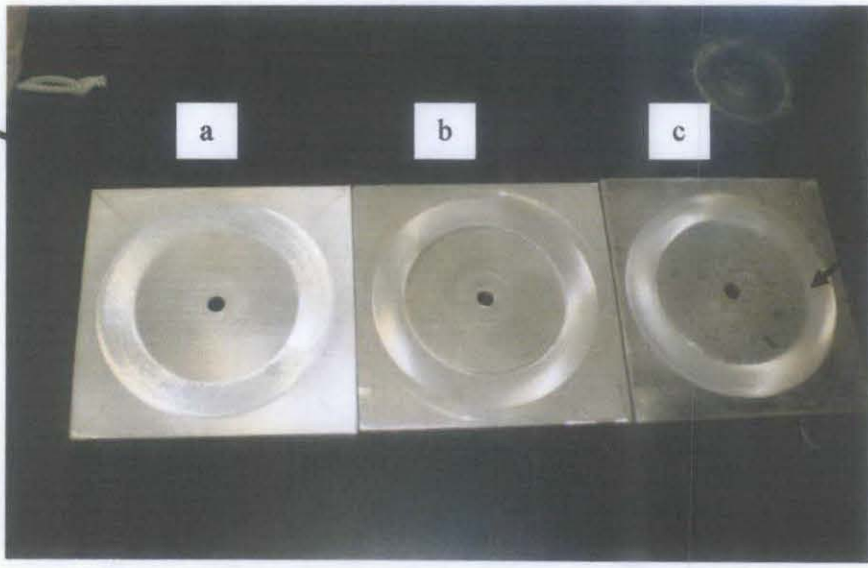


Figure 47: The Sample after Abrasion Wear Testing - a)Aluminum 6063, b) Stainless Steel 316, c) Mild Steel

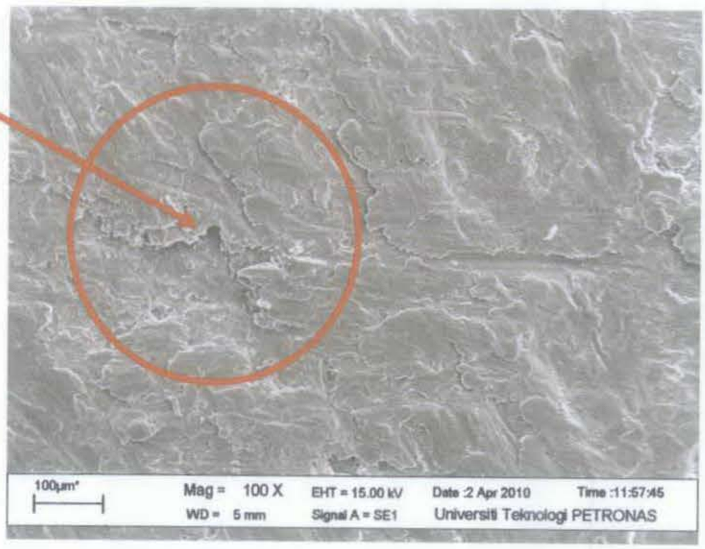


Figure 48: Visualization of Aluminum 6063 after testing using SEM Mag =100X

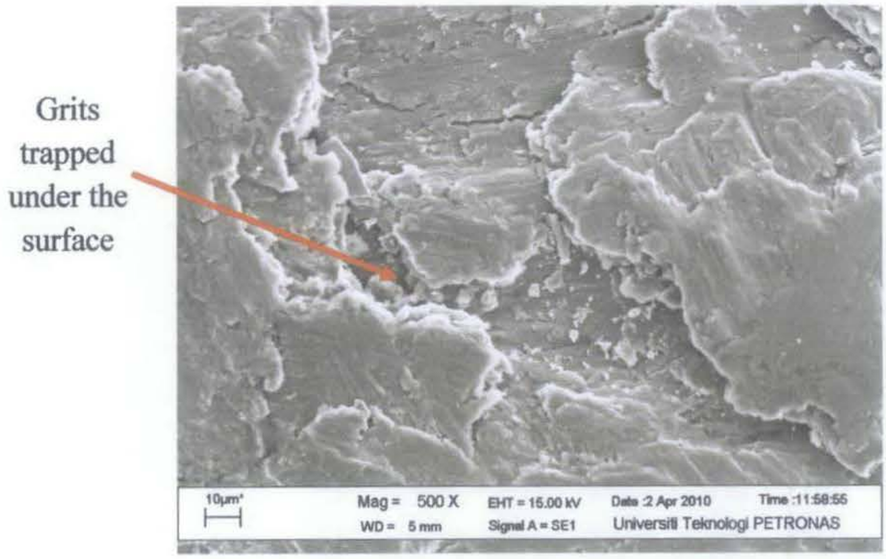


Figure 49: Visualization of Aluminum 6063 after testing using SEM Mag =500X

Figure 50: Visualization of Mild Steel after testing using SEM Mag =100X

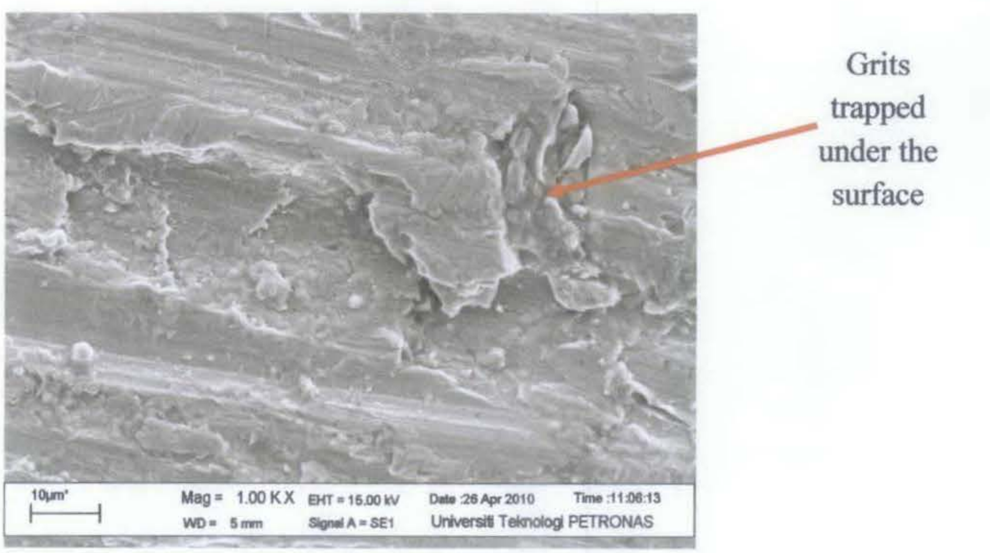


Figure 51: Visualization of Mild Steel after testing using SEM Mag =1000X

The least random surface profile between the samples

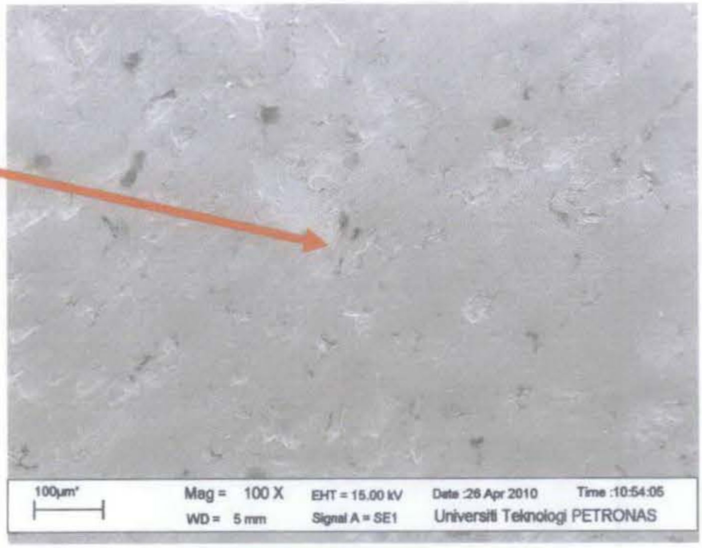


Figure 52: Visualization of Stainless Steel after testing using SEM Mag =100X

Grits trapped under the surface

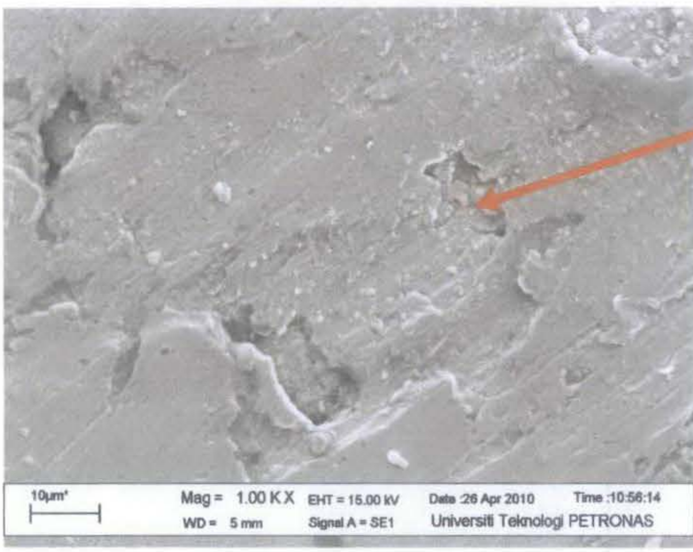


Figure 53: Visualization of Stainless Steel after testing using SEM Mag =1000X

As shown in Figure 48, 50 and 52, the surface profile is quite smooth compare to two body abrasion. When the magnifying value is increased as in Figure 49, 51, and 53, they had shown that some of the grits were basically trapped under the surface. It may cause by the gradual removal of surface layer by the successive contacts of the grits. This also might be the reason of slower abrasive wear rate of third body abrasion compare to the two body abrasion. As be influenced by the hardness, Stainless Steel 316 still has the higher abrasive wear resistance for third body abrasion followed by the Mild Steel and Aluminum 6063 accordingly.

4.6 Summary

Based on the three major testing (Taber Linear, Taber Rotary-2 Body Abrasion, Taber Rotary-3 Body Abrasion) done, the data proved that the abrasive resistivity of a material is relatively influenced by its hardness. If a material has a higher hardness value and the lower Taber Wear Index value, the material would have a better resistivity to abrasive wear. Archard reported that wear rates of some material vary linearly with the applied load and are independent of pressure over a wide range [11]. As the load increase, it will decrease the resistivity of a material to the abrasive wear. A material tends to have a lower resistivity with abrasive wear when experiencing high number of cycle, heavier load and less hardness material. Surface profile change of a material also depends on the abrasive resistance of material and the hardness of the materials itself.

The third body abrasion effect is actually slower compared to two body abrasion. The weight loss, hardness change, surface profile changes for two body abrasion is slightly higher compared to three body abrasion mechanism. Properties such as hardness of the backing wheel, which forces the grits onto a particular surface, were found to be important for three-body but not for two-body abrasive wear [1]. Two-body abrasive wear corresponds closely to the cutting tool model of material removal whereas three-body abrasive wear involves slower mechanisms of material removal through very little is known about the mechanisms involved [6]. It appears that the worn material is not removed by a series of scratches as is the case with two-body abrasive wear. Instead, the worn surface displays a random topography suggesting gradual removal of surface layers by the successive contact of grits [7]. Table 26 simplifies the Optical Microscope result for all the experiments. Based on Table 26, it has been proven that the difference for each abrasive modes for every particular samples.

There are many ways to control the abrasive wear effect on the surface of a material. This would be important to ensure the longevity service life of the equipments. For most practical metals the wear-resistance is controlled by work hardening. For technically pure metal wear resistance is proportional to hardness in the fully annealed condition. However, hardness is only effective in increasing abrasion resistance of the value is greater than about half of the abrasive hardness. Next, surface treatments or coatings can be used to provide improved abrasion resistance, but the depth must be related to the permissible wear depth [20]. Lubricant, coolant and metalworking fluid also would be a good way to prevent abrasive wear resistance. This is because they can actually carry away swarf (preventing loading), transport heat (which may affect the physical properties of the workpiece or the abrasive), decrease friction (with the substrate or matrix) and suspend worn work material for allowing a finer finished surface [21].

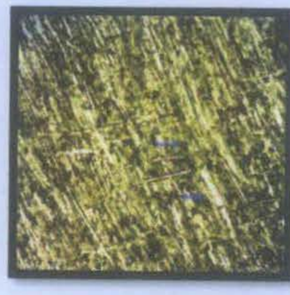
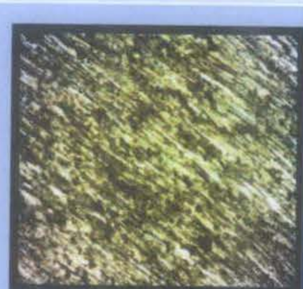
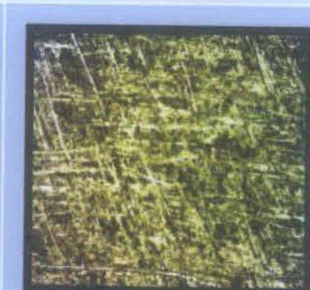
Testing / Material	Aluminum 6063	Mild Steel	Stainless Steel 316
Taber Linear			
Taber Rotary Two Body			
Taber Rotary Three Body			

Table 26: Optical Microscope result for all the experiments

Chapter 5

CONCLUSION AND RECOMMENDATIONS

This project is an integration of theoretical and laboratory works about the abrasive resistance in metallic materials. Based on the methodology and Gantt chart, all the project activities have been planned and done properly.

Stainless Steel 316 has higher resistance to abrasive wear compared to Aluminum 6063, and Mild Steel based on the Taber Wear index using Volume Loss Method. Hardness of a material really influenced the resistivity of material to abrasive wear. The higher the hardness of the material, the lower surface roughness changes when experiencing the abrasive wear conditions. This is the result under 1000N loads and 300 cycles for Taber Rotary 2 body abrasion, Taber Rotary 3 body abrasion and Table Linear Abraser:

Material/Parameter	Taber Wear Index	Δ Surface Roughness, R_a	Δ Hardness
Aluminum 6063	126.49	2.860	4.87
Mild Steel	78.234	0.887	4.37
Stainless Steel 316	28.83	0.513	1.57

Material/Parameter	Taber Wear Index	Δ Surface Roughness, R_a	Δ Hardness
Aluminum 6063	115.32	2.17	4.2
Mild Steel	71.92	0.60	3.53
Stainless Steel 316	26.49	0.39	1.00

Material/Parameter	Taber Wear Index	Δ Surface Roughness, R_a	Δ Hardness
Aluminum 6063	4.44	0.95	1.77
Mild Steel	3.14	0.86	2.33
Stainless Steel 316	1.26	0.49	2.87

Table 27: Summary of Results

As a conclusion, abrasive wear resistance is really crucial issue to be investigated. If this topic been studied carefully, the parts in the component can prevent and avoid themselves from experiencing the material lost due to abrasive wear. It is really beneficial as it will increase the performance and the durability of the components.

Recommendations

For this Project, there would be several improvements could be done to improvise this research. It would be important to enhance the quality of finding for abrasive wear resistance testing.

For Facilities and equipments;

The lab should be equipped with more facilities and equipments. For example, for Taber Abraser, various loads would bring significant difference in this research. The various loads might provide different results during the testing process. There also need to be a small sawing machine to cut a smaller sample. An abrasive cutter would not be a best solution, since it will affect the sample especially in term of heat distributions. It would also be necessary to have sieve with several small sizes of mesh. Thus, with the availability of several small sizes of mesh, various sizes of grits can be used to enhance the quality of finding for third body abrasion testing.

For Testing:

It would be more efficient if the number of cycles is increased to thousands number of cycles. The result for the high number of cycles would show the durability of the materials for abrasive wear in term of long duration time. The testing also could be done on elevated temperature as it will verified more regarding the characteristic of abrasive wear. If the testing could be done on lubrication and slurry environment it would be really beneficial. This is because; this type of environment will show different characteristics of abrasive than in usually testing environment.

As all the recommendation is taking into account, the research quality would be enhanced tremendously. These recommendations will help in increasing the understanding and quality of the research in identifying and analyzing the behavior of abrasive wear resistance for metallic materials. After the testing has been done based on the recommendations suggested, it will help in the material selection process particularly for the future developments in the industry.

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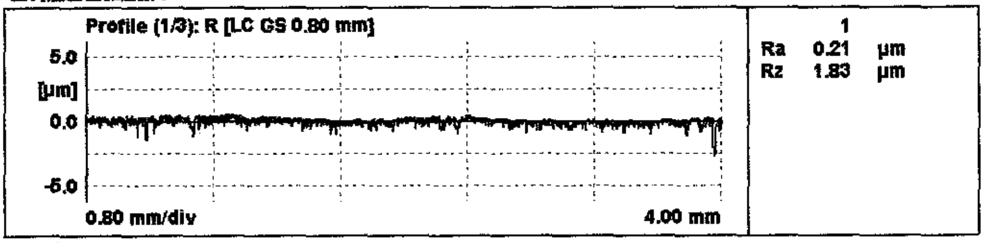
Appendix 1-A

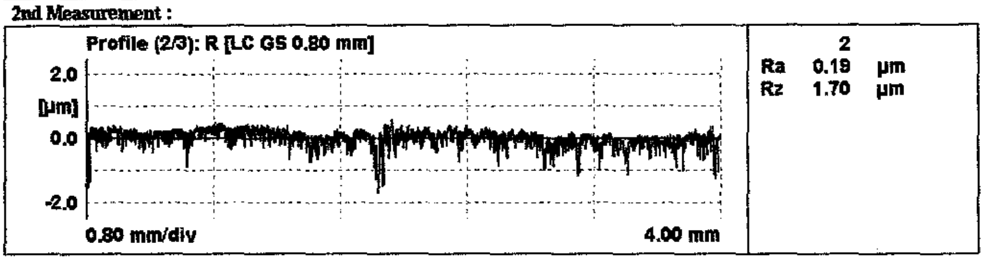
1.1 Taber Linear

<u>Surface Roughness Reading for Stainless Steel 316 before Testing</u>

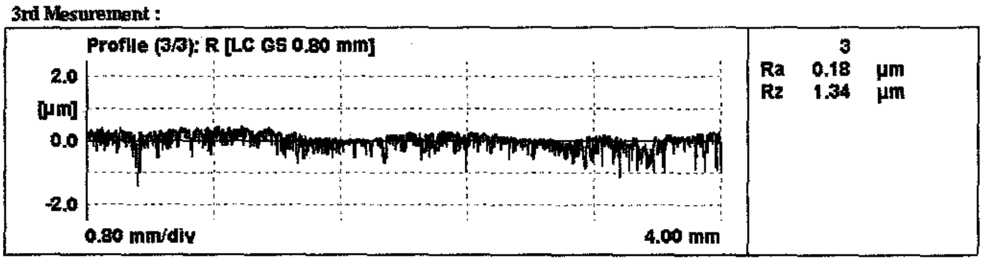
1st Measurement :



2nd Measurement :

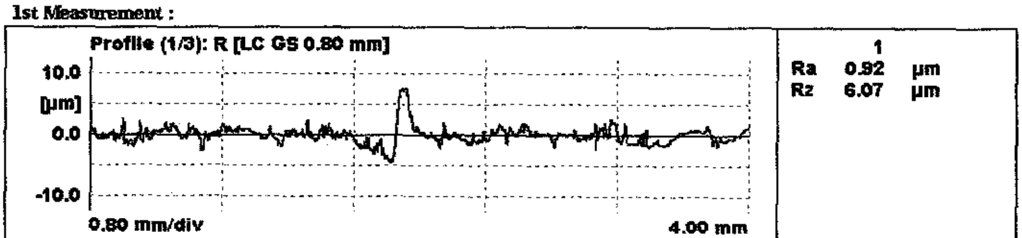


3rd Mesurement :

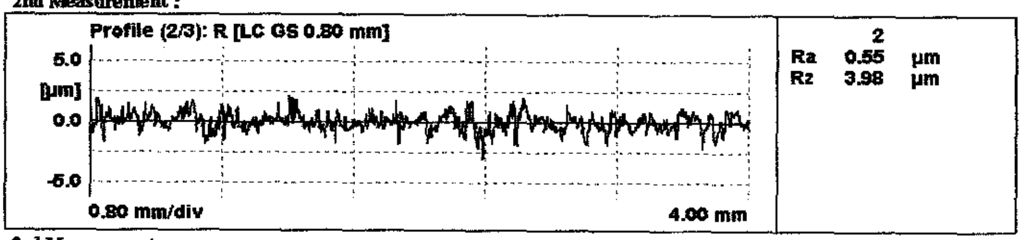


<u>Surface Roughness Reading for Stainless Steel 316 after Testing</u>

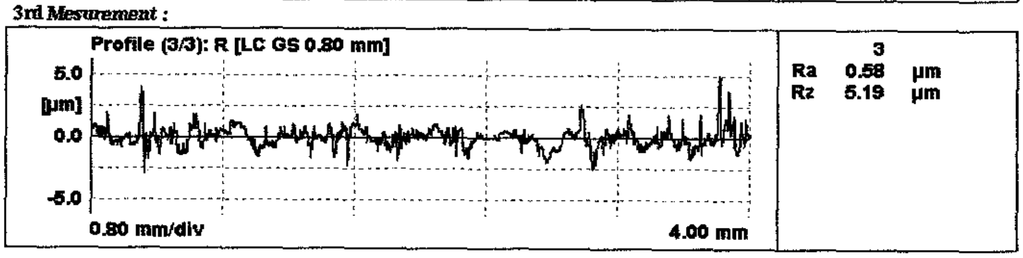
1st Measurement :



2nd Measurement :



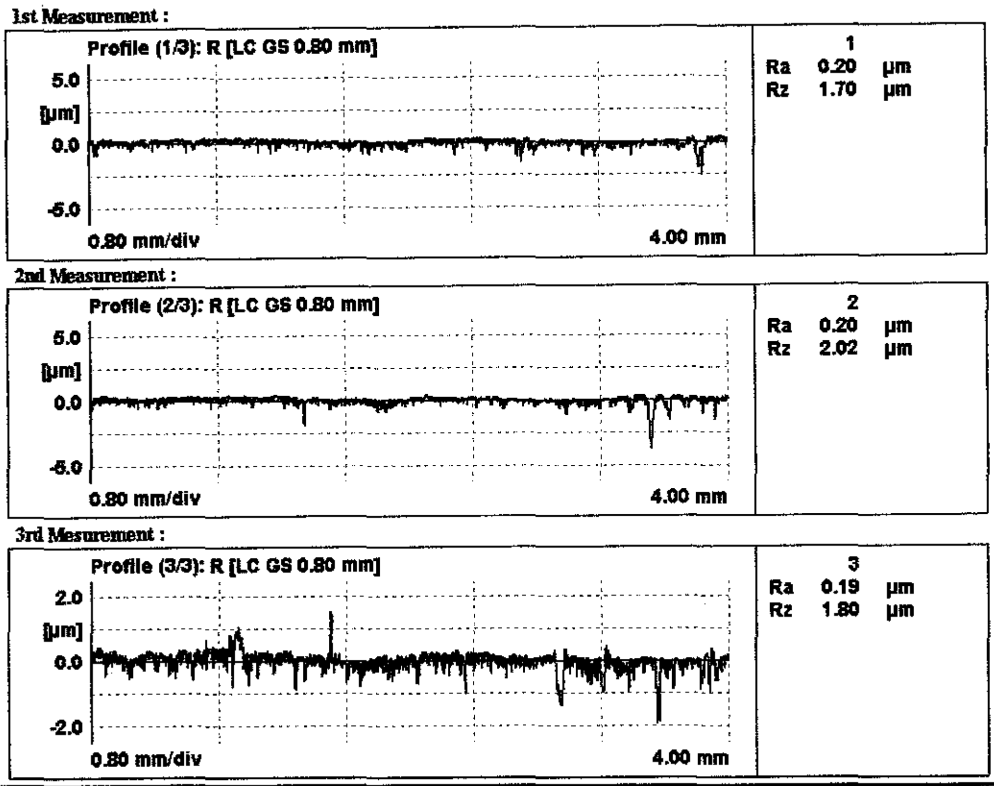
3rd Mesurement :



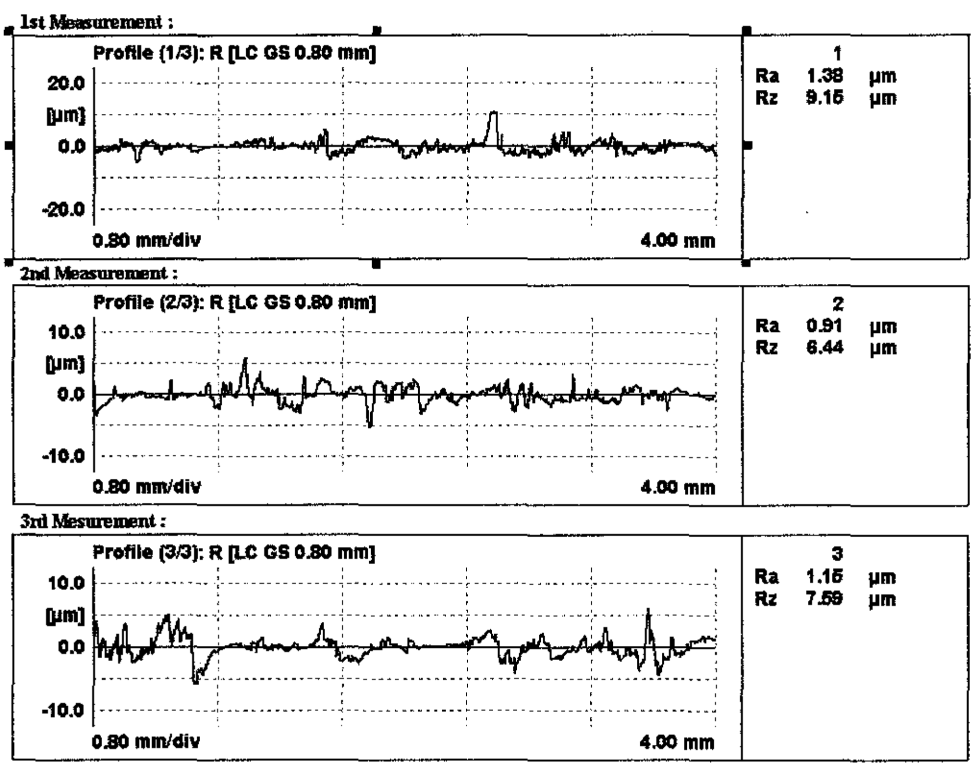
Appendix 1-A

1.2 Taber Linear

Surface Roughness Reading for Aluminum 6063 before Testing



Surface Roughness Reading for Aluminum 6063 after Testing

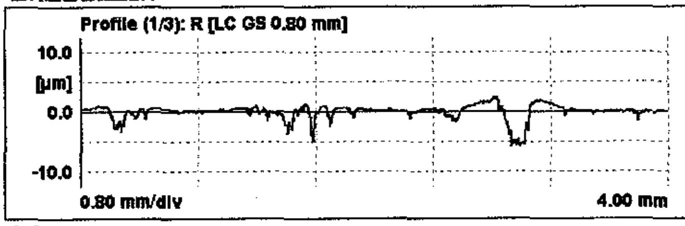


Appendix 1-A

1.3 Taber Linear

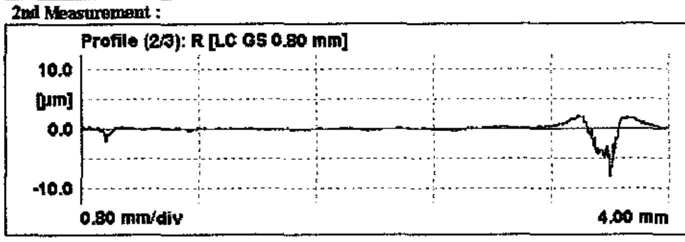
Surface Roughness Reading for Mild Steel before Testing

1st Measurement :



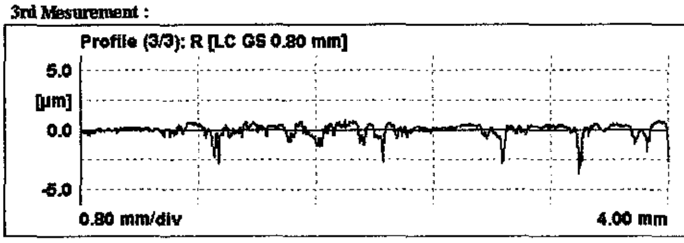
1		
Ra	0.73	µm
Rz	5.01	µm

2nd Measurement :



2		
Ra	0.44	µm
Rz	2.97	µm

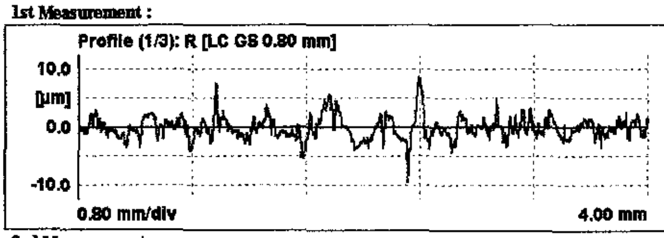
3rd Mesurement :



3		
Ra	0.35	µm
Rz	3.24	µm

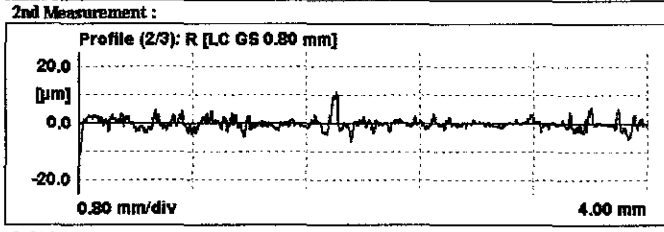
Surface Roughness Reading for Mild Steel after Testing

1st Measurement :



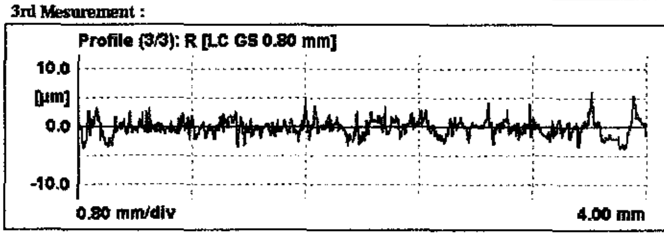
1		
Ra	1.42	µm
Rz	11.50	µm

2nd Measurement :



2		
Ra	1.30	µm
Rz	11.66	µm

3rd Mesurement :



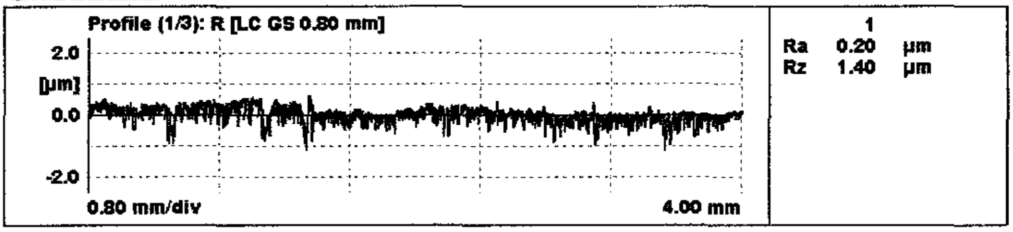
3		
Ra	1.07	µm
Rz	8.03	µm

Appendix 1-B

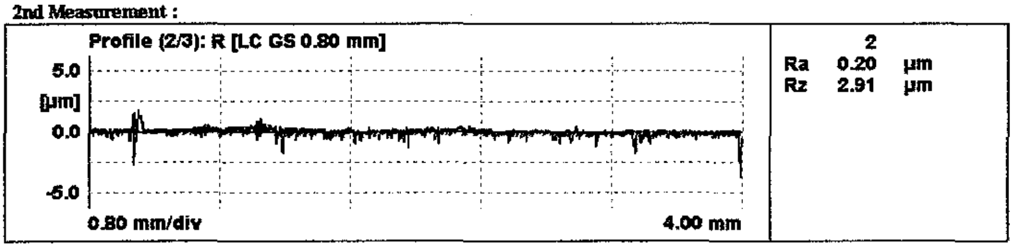
1.1 Taber Rotary -2 Body Abrasion

Surface Roughness Reading for Stainless Steel 316 before Testing

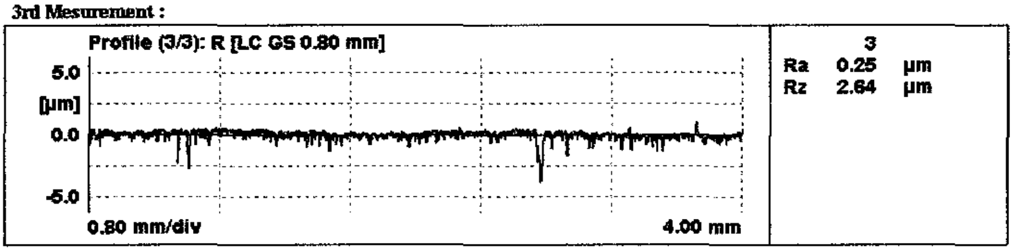
1st Measurement :



2nd Measurement :

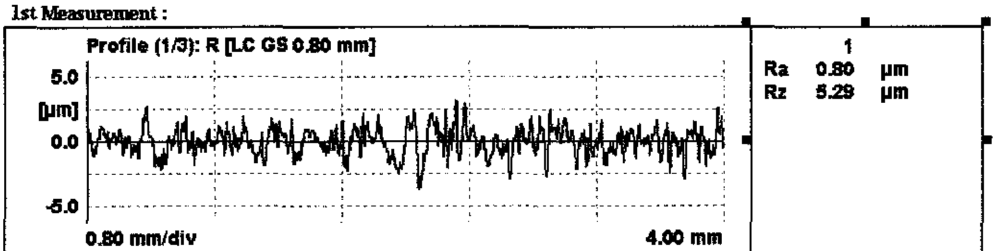


3rd Mesurement :

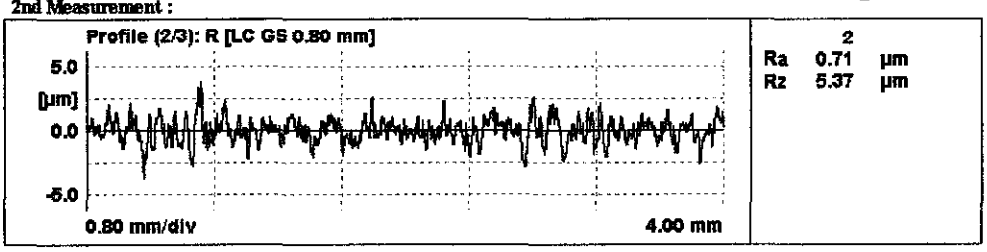


Surface Roughness Reading for Stainless Steel 316 after Testing

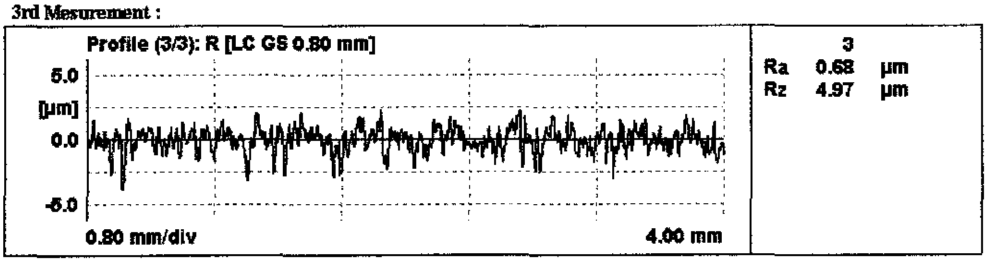
1st Measurement :



2nd Measurement :



3rd Mesurement :

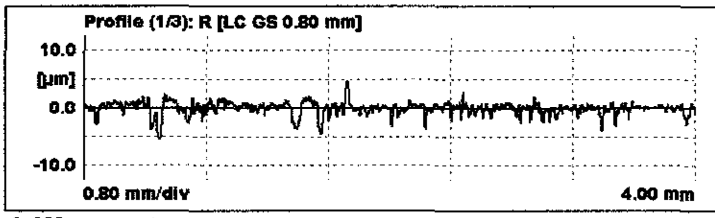


Appendix 1-B

1.2 Taber Rotary -2 Body Abrasion

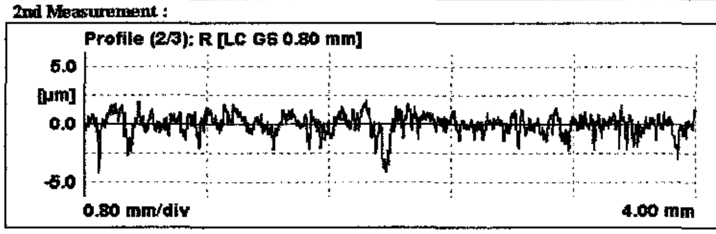
Surface Roughness Reading for Aluminum 6063 before Testing

1st Measurement :



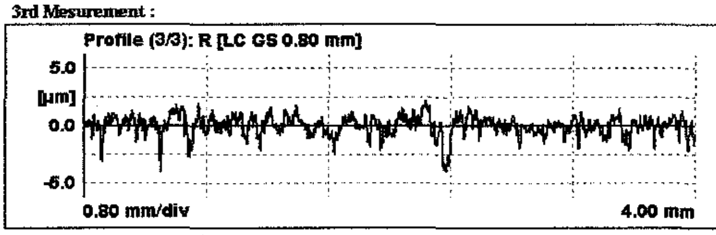
1		
Ra	0.76	µm
Rz	6.64	µm

2nd Measurement :



2		
Ra	0.64	µm
Rz	4.94	µm

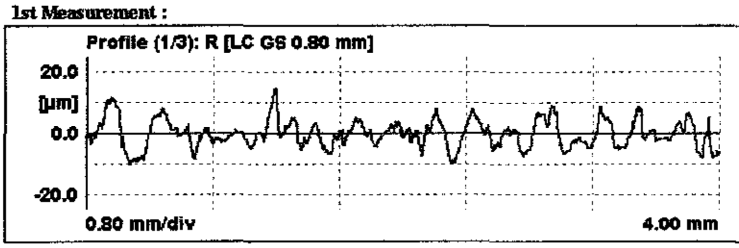
3rd Mesurement :



3		
Ra	0.63	µm
Rz	4.63	µm

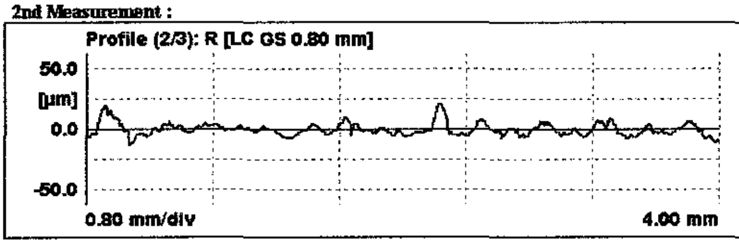
Surface Roughness Reading for Aluminum 6063 after Testing

1st Measurement :



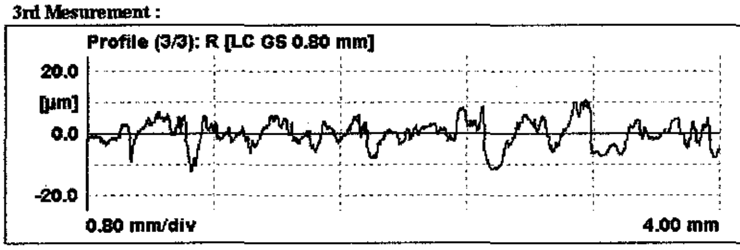
1		
Ra	3.51	µm
Rz	18.81	µm

2nd Measurement :



2		
Ra	3.84	µm
Rz	21.63	µm

3rd Mesurement :



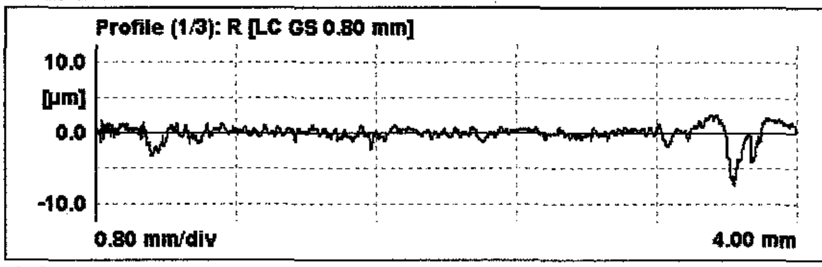
3		
Ra	3.26	µm
Rz	16.45	µm

Appendix 1-B

1.3 Taber Rotary -2 Body Abrasion

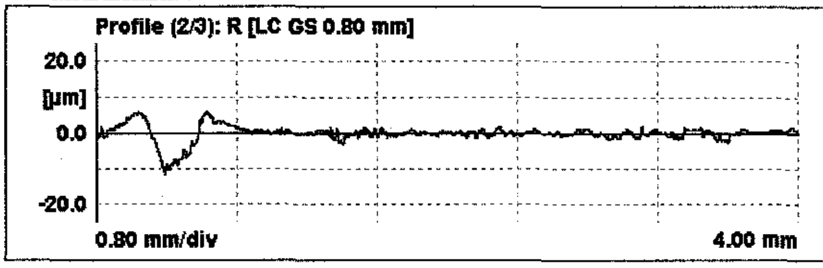
Surface Roughness Reading for Mild Steel before Testing

1st Measurement :



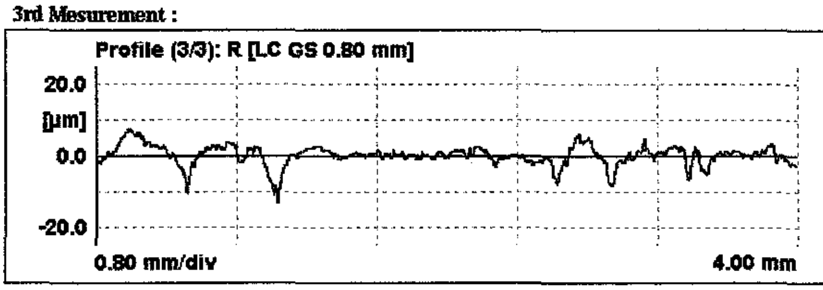
1		
Ra	0.73	µm
Rz	4.62	µm

2nd Measurement :



2		
Ra	1.28	µm
Rz	6.74	µm

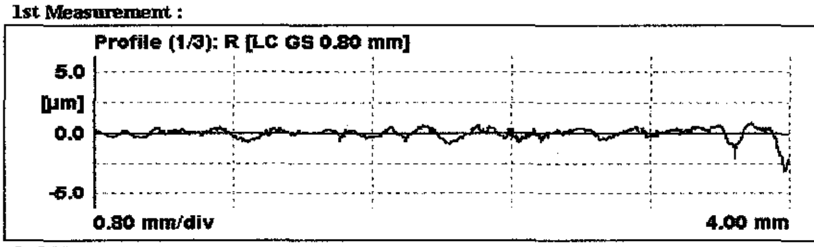
3rd Mesurement :



3		
Ra	1.95	µm
Rz	12.78	µm

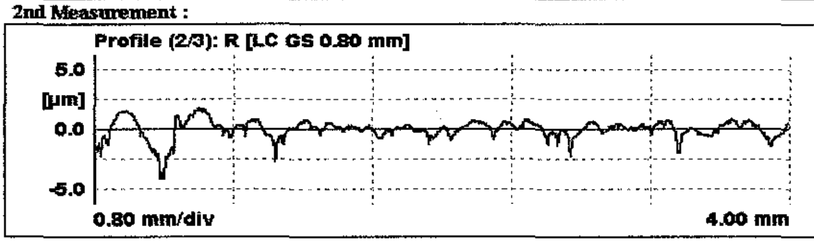
Surface Roughness Reading for Mild Steel after Testing

1st Measurement :



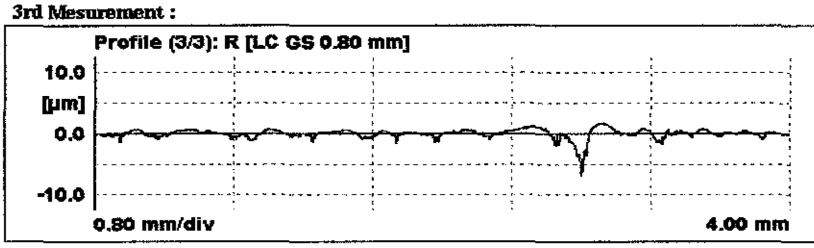
1		
Ra	0.30	µm
Rz	1.75	µm

2nd Measurement :



2		
Ra	0.54	µm
Rz	3.47	µm

3rd Mesurement :



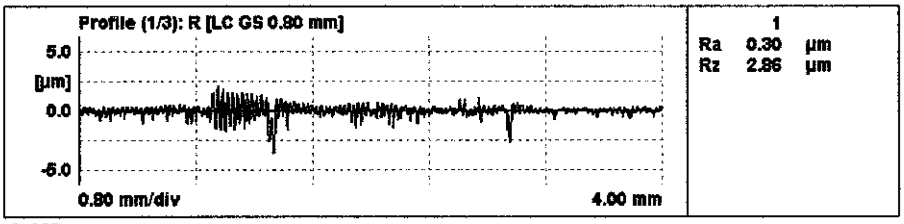
3		
Ra	0.46	µm
Rz	3.44	µm

Appendix 1-C

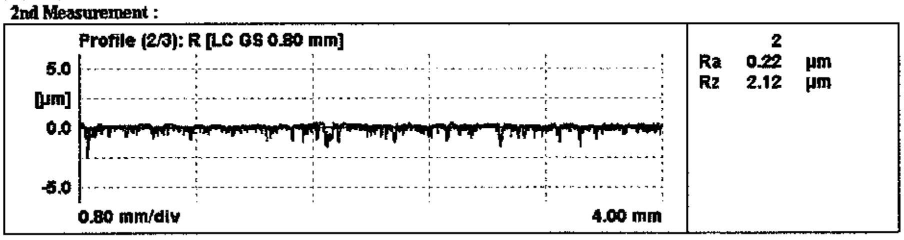
1.1 Taber Rotary - 3 Body Abrasion

Surface Roughness Reading for Stainless Steel 316 before Testing

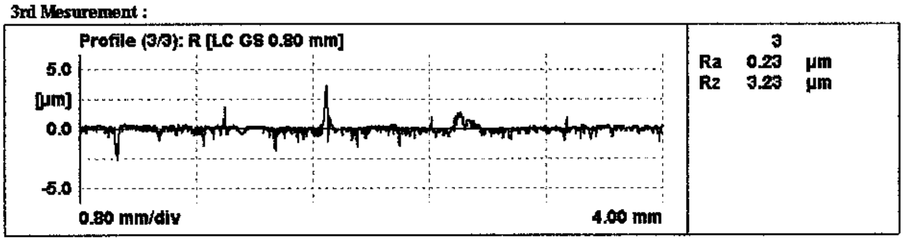
1st Measurement :



2nd Measurement :

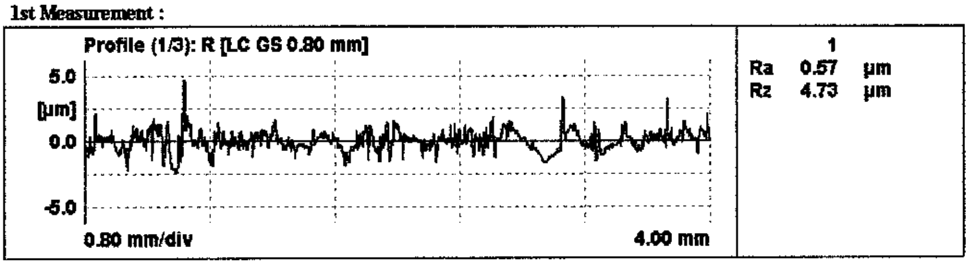


3rd Mesurement :

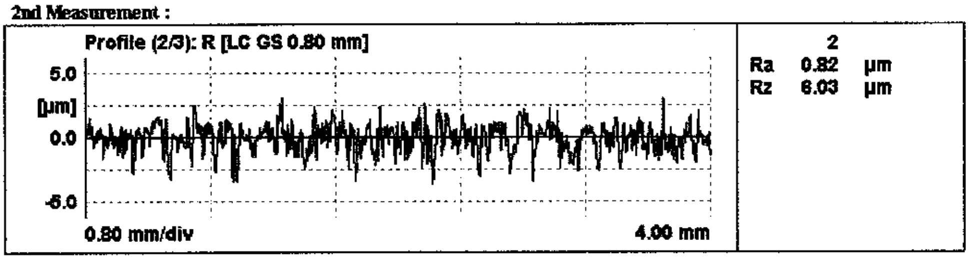


Surface Roughness Reading for Stainless Steel 316 after Testing

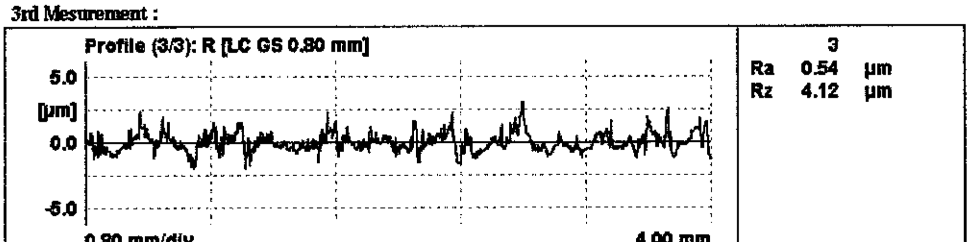
1st Measurement :



2nd Measurement :



3rd Mesurement :

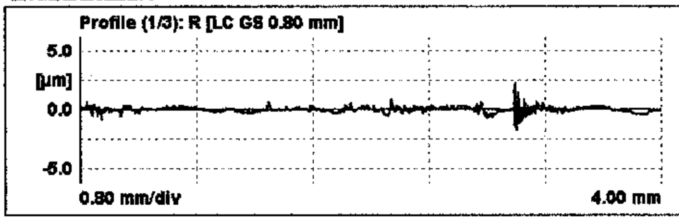


Appendix 1-C

1.2 Taber Rotary - 3 Body Abrasion

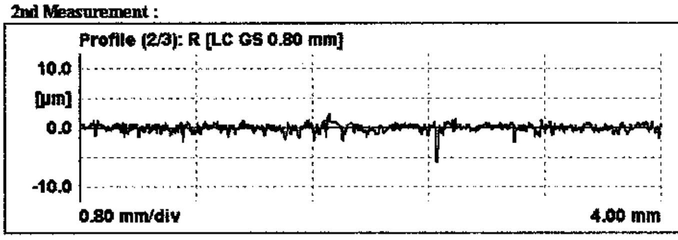
Surface Roughness Reading for Aluminum 6063 before Testing

1st Measurement :



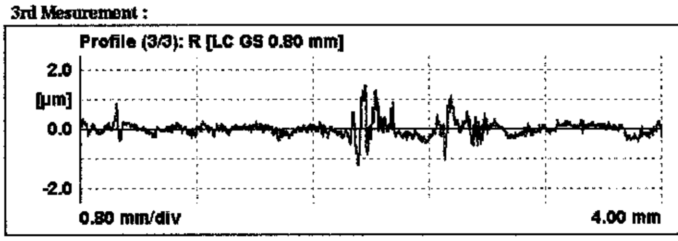
1
Ra 0.17 µm
Rz 1.74 µm

2nd Measurement :



2
Ra 0.49 µm
Rz 4.36 µm

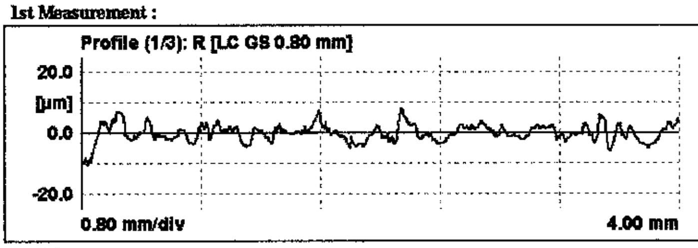
3rd Mesurement :



3
Ra 0.17 µm
Rz 1.61 µm

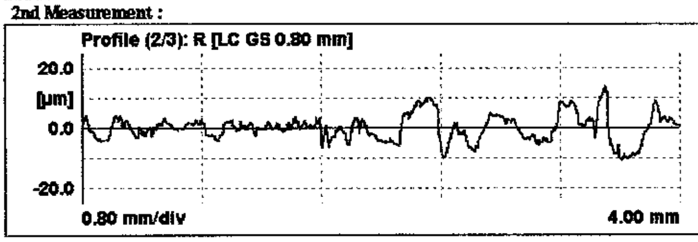
Surface Roughness Reading for Aluminum 6063 after Testing

1st Measurement :



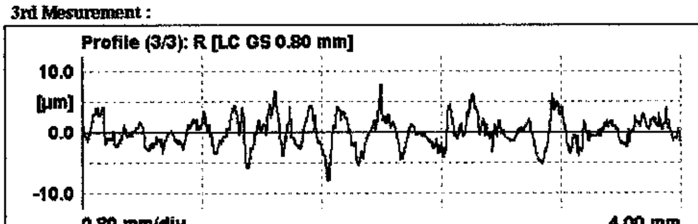
1
Ra 2.17 µm
Rz 12.45 µm

2nd Measurement :



2
Ra 3.31 µm
Rz 15.44 µm

3rd Mesurement :



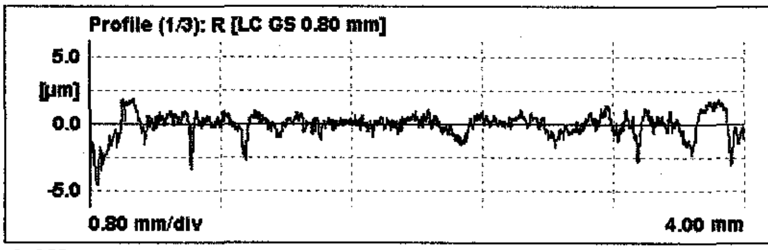
3
Ra 1.86 µm
Rz 11.18 µm

Appendix 1-C

1.3 Taber Rotary - 3 Body Abrasion

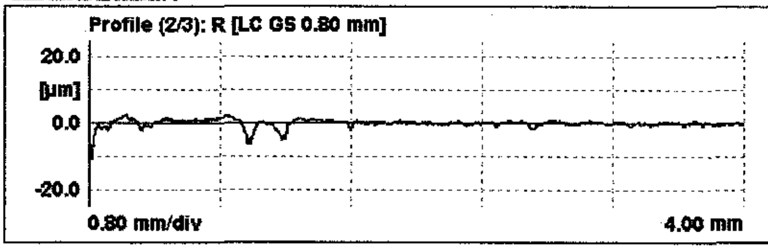
<u>Surface Roughness Reading for Mild Steel before Testing</u>

1st Measurement :



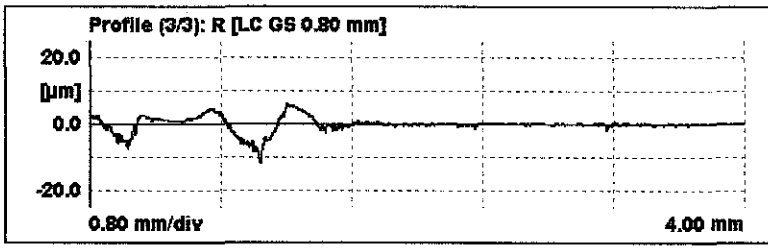
1
Ra 0.61 µm
Rz 4.17 µm

2nd Measurement :



2
Ra 0.71 µm
Rz 5.95 µm

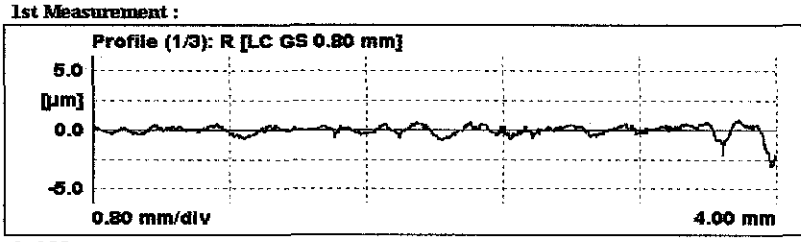
3rd Mesurement :



3
Ra 1.25 µm
Rz 7.14 µm

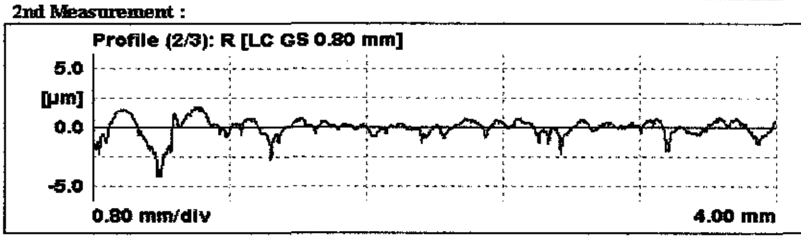
<u>Surface Roughness Reading for Mild Steel after Testing</u>

1st Measurement :



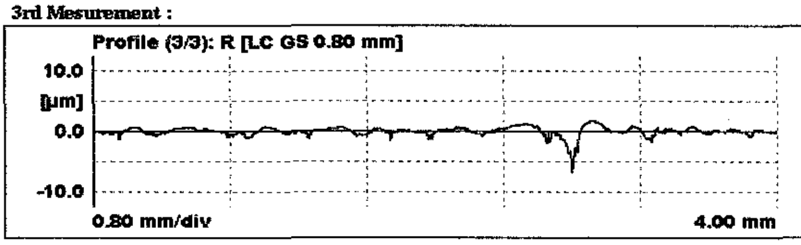
1
Ra 0.30 µm
Rz 1.75 µm

2nd Measurement :



2
Ra 0.54 µm
Rz 3.47 µm

3rd Mesurement :



3
Ra 0.46 µm
Rz 3.44 µm